chapter

10 Hydrocarbon Derivatives, Organic Reactions, and Petrochemicals

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Alberta's resources contribute to making this province one of the best places in the world to live and work. Alberta's resource wealth includes a diverse, well-educated population, an environment that brings tourists in all seasons, and petroleum reserves. You may not realize it, but all of these resources depend on organic chemicals and the reactions that this unique class of chemicals can undergo.

When the price of natural gas, crude oil, and gasoline increases, the price of almost everything else likewise increases—evidence for the strong connection between fossil fuels and many other products. Chemicals that are produced from petroleum are called *petrochemicals*. Petrochemicals include plastics, asphalt shingles, paints, dyes, cosmetics, antifreezes, lubricants, adhesives, carpets, pesticides, fertilizers, and pharmaceuticals.

Much of the petrochemical industry in Alberta is located near Sherwood Park, Fort Saskatchewan, and Red Deer. Both natural gas and crude oil are the raw materials that, when refined, supply the petrochemical feedstock. Ninety-five percent of refined crude oil and natural gas is burned. The other five percent is used as petrochemical *feedstock*. Feedstock is a variety of chemical substances used in the chemical processes to produce petrochemicals. The end products are in demand by industry, commerce, and consumers.

Some of the main petrochemical feedstocks derived from natural gas are methane, ethane, propane, and butane. The main feedstocks from crude oil are naphtha and gas oil. Organic reactions convert these hydrocarbon feedstocks to petrochemicals. In this chapter, you will learn how to describe, explain, and predict organic reactions. As with any undertaking, there are risks and benefits to the development of petrochemical industries in Alberta. Throughout this chapter, you are asked to adopt a multiperspective view and to gather information for and against this industrial development.

STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. What reactions, other than combustion and cracking, do organic compounds undergo?
2. List some important consumer, commercial and/or industrial petrochemical products of organic reactions.
3. What are polymers? Give some specific examples.

Career Connection:
Chemical Engineer; Chemical Employee

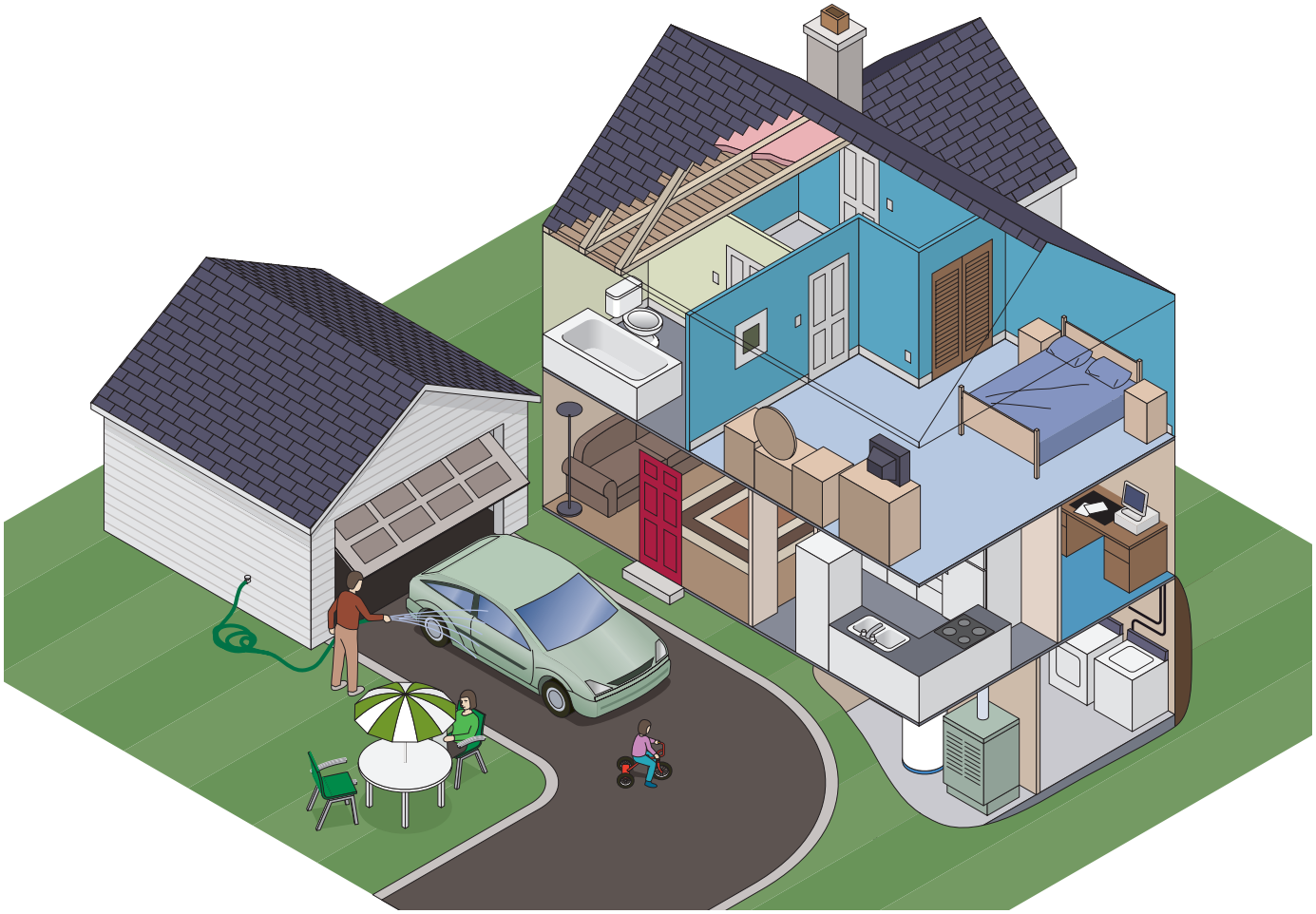

Figure 1
Chemicals from petroleum—petrochemicals—are everywhere around us. There are at least twenty different petrochemical products in this illustration, such as synthetic fabrics in bedding, countertops, rugs, vinyl flooring, garden hose, chairs, and siding. What are some other examples?

Exploration — Burning Fossil Fuels

This Exploration continues from Chapter 9. In this chapter (which looks at the production of petrochemicals from petroleum), the emphasis is on the second, boldfaced, statement below.

Scientists agree that fossil fuels are a nonrenewable, finite resource. Fossil fuels in Alberta include coal, natural gas, crude oil, oil sands, and heavy oil. Studies have indicated that about 95% of the fossil fuels used in Alberta are used for energy production, including natural gas and propane for home heating, and gasoline and diesel fuel for cars, trucks, and buses. The evidence indicates that about 5% of fossil fuels are converted into petrochemicals (such as plastics) through technologies based on chemical reactions. Two issues related to burning fossil fuels for energy production are

- whether we should be burning a very valuable resource at the rate that we are
- **whether we should be saving more of this resource for petrochemical use in the future**

Issue Checklist

○ Issue	● Design	● Analysis
○ Resolution	● Evidence	● Evaluation

Resolution: We should be saving more fossil fuels for future use as petrochemicals.

While progressing through Chapter 10, complete the Design, Evidence, Analysis, and Evaluation components of this second issue report. Specific to this chapter, the evidence includes a list of important organic reactions that produce valued petrochemicals.

Governments, industry, and citizens alike speak of sustainable development. The United Nations Commission on Environment and Development defines sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Keep this concept in mind while completing this unit-long exploration.

10.1 Petrochemicals in Alberta

The petrochemical industry in Alberta is a secondary and tertiary industry that takes raw materials, such as crude oil and natural gas, and feedstocks, such as ethane, and converts them into value-added chemicals. This industry is an important economic and social addition to the fossil fuel, agriculture, and tourism industries of Alberta. The petrochemical industry in Alberta exports to other parts of Canada and the world. **Figure 1** depicts the raw materials, feedstock, and primary petrochemicals that start the chemical processes you will learn about in this chapter.

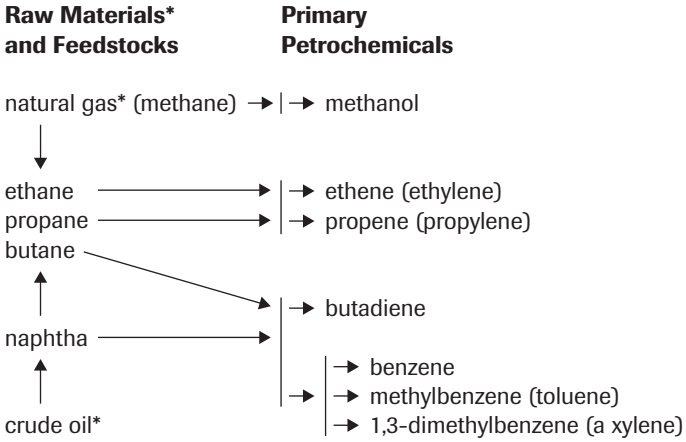

Figure 1
The sources of primary petrochemicals

Some of these primary petrochemicals have immediate uses, but most of them undergo further chemical reactions to produce chemical derivatives. For example, methanol has an immediate use as a fuel and as a windshield washer fluid and gas line antifreeze. Xylene is a chemical name that you find listed as an ingredient of solvents found in a hardware or lumber store. Ethene may be used directly for helping to ripen some varieties of fruits, but most of this primary petrochemical is used in chemical processes to produce polymers, such as polyethene.

CAREER CONNECTION

Chemical Engineer

The chemical industry is Canada's most knowledge-based industry. About 30% of workers in the chemical industry have university degrees. The salaries in the chemical industry are, as expected, among the highest in Canada. What types of chemical industries employ chemical engineers?

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DID YOU KNOW

A Keystone Industry

The chemical industry uses natural raw materials from the earth, water, and air to manufacture everyday products. The chemical industry produces more than 70 000 chemical products, including papers, pesticides, cleaning compounds, cosmetics, toiletries, paints, pharmaceuticals, and safe water.

Practice

1. The following chemicals are feedstocks for a petrochemical industry. Draw full structural formulas for each.
   (a) methane
   (b) ethane
   (c) propane
   (d) butane
2. Naphtha is a distillation fraction from crude, heavy, or synthetic oil.
   (a) What range of hydrocarbons is expected to be found in naphtha?
   (b) In what technological application(s) is naphtha burned?
3. The following chemicals are primary petrochemicals in a petrochemical industry. Draw line structural formulas for each:
   (a) methanol
   (b) ethene
   (c) propene
   (d) buta-1,3-diene ($CH_2CHCHCH_2(g)$)
   (e) benzene
   (f) methylbenzene
   (g) 1,3-dimethylbenzene

Primary Petrochemicals

Chemical engineers use the primary petrochemicals in **Figure 1** to produce the intermediates and derivatives in **Figure 2**. Notice the extensive petrochemical industry that can be created from a few basic chemical building blocks—from primary petrochemicals obtained from crude oil and natural gas. Many new compounds can be made by adding other substituents (such as chlorine and oxygen), changing the bonding, or joining small molecules together. You will learn about polymers (listed mostly in the last column of Figure 2) in Section 10.5.

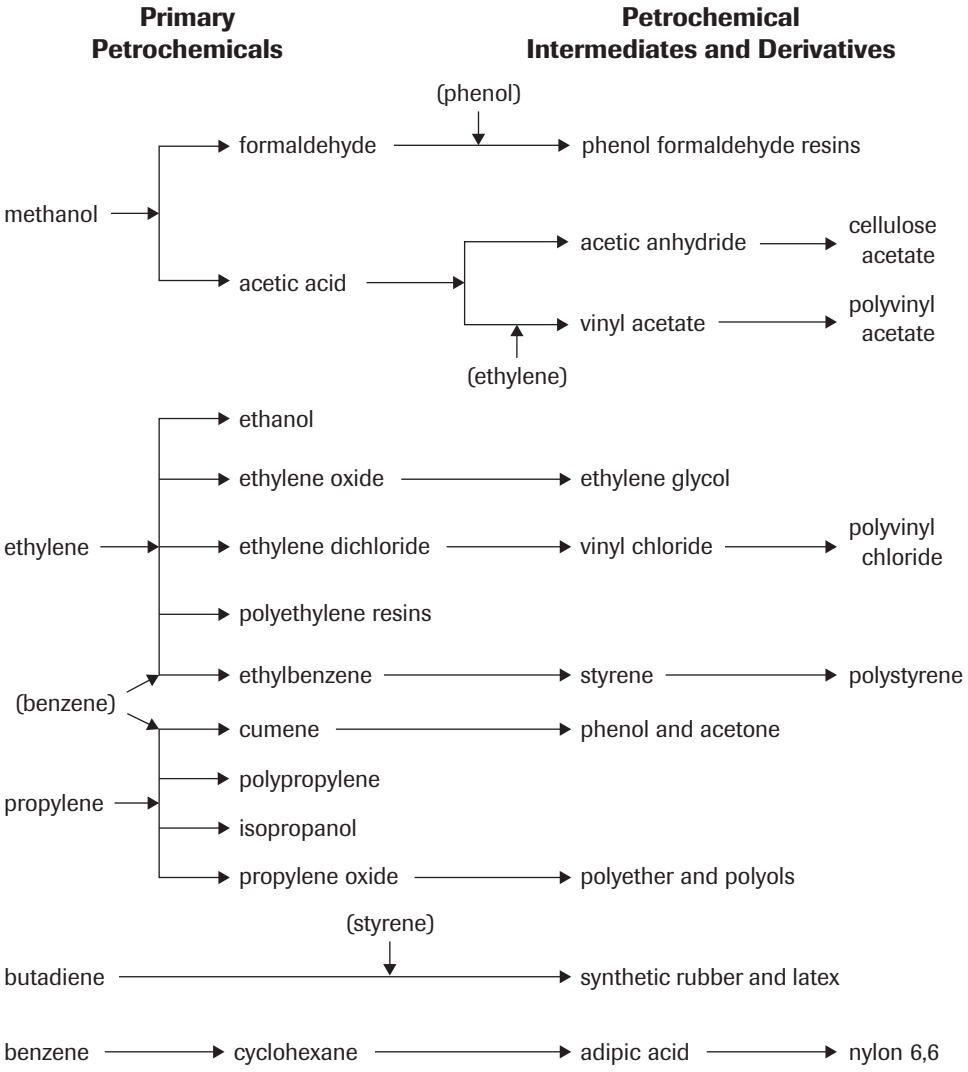

Figure 2
This figure, provided by industry, communicates primary petrochemicals, intermediates, and derivatives. You do not have to memorize this figure, or the common industrial names (except acetic acid, ethylene, and propylene). Most of these common names are translated into systematic IUPAC names in the exercise below.

DID YOU KNOW ?

Natural Gas Consumption

Chemical operators account for over half of the natural gas consumption in Alberta. This consumption includes the extraction and refining of fossil fuels, as well as the processing of refined fossil fuels into petrochemicals. As oil sands projects multiply, the consumption of natural gas by industry is likely to increase significantly. Most of the natural gas is used for heat and power. Only about 5% is converted directly into petrochemicals.

Practice

4. Draw structural formulas for the following list of intermediate, reagent, and derivative chemicals from **Figure 2**. Follow the bonding capacity of each element. The molecular formula is not given if you should know it. You might want to reconstruct Figure 2 in your notebook using full structural formulas. The chemicals marked with an asterisk (*) are ones that you will know by the end of this chapter.

(a) formaldehyde is methanal, HCHO(l)
(b) phenol is hydroxybenzene, $C_6H_5OH(s)$*
(c) acetic acid is ethanoic acid, $CH_3COOH(l)$*
(d) acetic anhydride is $(CH_3CO)_2O(l)$

(e) vinyl acetate is $CH_2CHOOCCH_3(l)$
(f) ethanol
(g) ethylene oxide is $(CH_2)_2O(g)$
(h) ethylene glycol is 1,2-dihydroxyethane, $CH_2OHCH_2OH(l)$*
(i) ethylene dichloride is 1,2-dichloroethane, $CH_2ClCH_2Cl(l)$
(j) vinyl chloride is chloroethene, $C_2H_3Cl(g)$*
(k) ethylbenzene (a full and line structural formula hybrid is okay for (k) and (l))
(l) styrene is vinylbenzene (phenylethene)*
(m) cumene is 2-phenylpropane
(n) acetone is propan-2-one, $CH_3COCH_3(l)$
(o) isopropanol is propan-2-ol, $CH_3CHOHCH_3(l)$*
(p) propylene oxide is $CH_3CHOCH_2(l)$
(q) cyclohexane
(r) adipic acid is hexane-1,6-dioic acid, $HOOC(CH_2)_4COOH(s)$

5. All of the chemicals in question 4 are involved in organic chemical reactions. Choose any two of the reactions from **Figure 1** or **Figure 2** and hypothesize a balanced chemical equation for the reactions; e.g., methanol to acetic acid, ethene to ethanol, ethene to styrene, and/or benzene to cyclohexane.
6. Polymers are long-chain molecules that can be made into plastics and synthetic fabrics. List six chemicals from Figure 2 that you think might be classified as polymers (e.g., polyethylene).
7. In 2002, Statistics Canada listed the sales of chemicals in Canada, in billions of dollars (**Table 1**). Create a pie chart to represent the percent sales for each category.
8. Use a reference to find some physical properties of two of the chemicals listed in **Figure 1** or **Figure 2**; e.g., styrene, ethylene dichloride, acetic acid, vinyl chloride, and/or formaldehyde.

Table 1 Chemical Sales in Canada

Chemical	Sales (G$)
basic*	20.2
soaps	1.8
fertilizers	2.5
paints	2.0
toiletries	1.3
pharmaceuticals	7.5
adhesives	0.6
inks	0.4
other	3.9

* basic chemicals and resins (for plastics)

DID YOU KNOW ?

Largest in Canada

After food production, the petrochemical industry is the second largest manufacturing sector in Alberta. Alberta is Canada's largest petrochemical producing area. The availability of energy, feedstock, and a highly educated population give Alberta an advantage over other regions in Canada.

Ethene and Its Derivatives

About 5% of our fossil fuels is used to produce petrochemicals. The economic importance of petrochemicals lies in the fact that basic raw materials are processed and reprocessed many times. For example, **Figure 3** shows the numbers of jobs in various industries that rely on petrochemicals. Ethene (ethylene) is one of the most important petrochemicals. For every 11 jobs involved in the manufacture of ethylene, 116 jobs are created in manufacturing the intermediate, vinyl chloride (chloroethene), 600 jobs in manufacturing the plastic polyvinyl chloride (PVC), and about 6000 jobs in manufacturing other commercial and consumer products, such as pipes and tiles.

As you learned in Chapter 9, ethene is produced in Alberta by cracking ethane that is extracted from natural gas (page 378). At one time, we burned the ethane in the natural gas without removing it. The natural gas that is burned now in consumer, commercial, and industrial settings, however, is likely to have had the ethane (and propane and butane) extracted. These gases are extracted as liquids and are called natural gas liquids (NGLs) or liquefied petroleum gases (LPGs). The remaining natural gas contains mostly methane.

In **Figure 2**, ethene (ethylene) is shown as undergoing reactions to produce ethanol, ethylene oxide, ethylene dichloride, polyethylene resins, and ethylbenzene. You will study some of these reactions, and others, in the pages that follow. **Table 2** gives the locations of some of the chemical plants that produce products related to ethane and ethene.

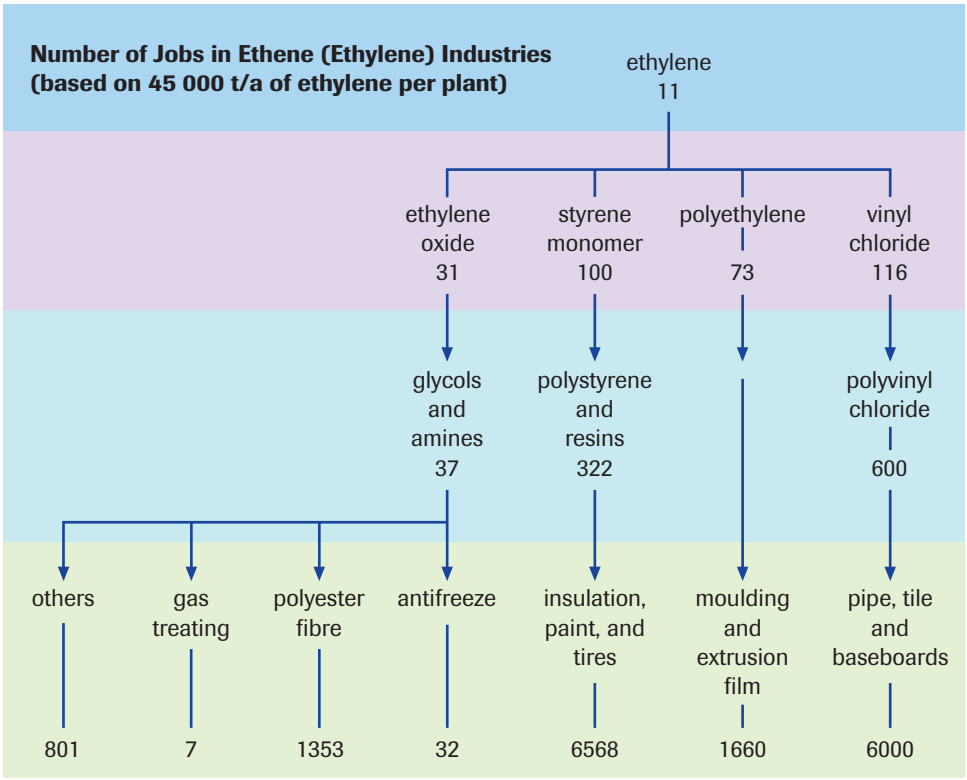

Figure 3
Number of jobs in ethene industries, based on 45 000 t/a of ethene per plant. This is called a multiplier effect. For every 11 jobs in the ethene plant, there are thousands of jobs created elsewhere.

Table 2 Alberta Chemical Operations (2006)

Chemical	Owner	Location in Alberta
ethane	Taylor NGL	Joffre (east of Red Deer)
	ATCO/Altagas	Edmonton
	Inter Pipeline (IPL)	Cochrane (west of Calgary)
	ATCO, EnCana, IPL, BP Canada, and Duke	Empress (6 plants straddling gas pipelines, northeast of Medicine Hat)
ethylene (ethene)	Dow Chemical	Fort Saskatchewan
	Nova Chemicals	Joffre (3 plants)
polyethylene	Dow Chemical	Prentiss (northeast of Red Deer), Fort Saskatchewan
	AT Plastics	Edmonton
	Nova Chemicals	Joffre (east of Red Deer)
styrene	Shell Chemicals	Scotford (east of Edmonton)
polystyrene	Dow Chemical	Fort Saskatchewan
vinyl chloride	Dow Chemical	Fort Saskatchewan
polyvinyl chloride	Oxy Vinyls	Fort Saskatchewan
ethylene glycol	Dow Chemical	Fort Saskatchewan, Prentiss
	Shell Chemical	Scotford (east of Edmonton)
ethylene dichloride	Dow Chemical	Fort Saskatchewan

CAREER CONNECTION

Chemical Employees

According to Statistics Canada, the chemical industry in Alberta employs 8000 full-time people directly. Each job in the chemical industry creates 2.5 additional jobs in the local economy; e.g., engineers, scientists, technologists, and trades and support personnel.

Research a chemical career that you might be interested in at the Alberta Learning Information Service (ALIS) Web site. Report on the type and years of education required, and the expected salary.

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Learning Tip

You are not expected to learn the names of the chemical companies nor their locations in Alberta. **Table 2** provides specific evidence that over 50% of Canada's petrochemical capacity is in Alberta. **Table 2** serves to reinforce the point that Alberta is a major petrochemical centre in Canada and could become a major centre in the world. All of the chemicals mentioned in **Table 2** are presented in greater detail later in this chapter.

EXTENSION

CBC radio ONE

QUIRKS & QUARKS

The End of Oil?

Are we close to running out of easily available petroleum resources, or do we have enough to meet our needs for centuries? Which would be the "better" scenario? Two writers voice their perspectives on the topic. Either way, you may be worried.

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SUMMARY Petrochemicals

- The petrochemical industry in Alberta and Canada contributes significantly to our economy.
- There are risks and benefits associated with every chemical—natural or manufactured.
- Ethane is obtained from natural gas, is cracked into ethene, and then the ethene is converted by chemical reactions into many other petrochemicals.
- Petrochemicals include plastics, paints, dyes, cosmetics, antifreezes, adhesives, carpets, fertilizers, and pharmaceuticals.
- There are many well-paying careers in the petrochemical industry.

Section 10.1 Questions

1. The chemicals listed in **Table 2**, Alberta Chemical Operations, are also listed in **Table 3**, along with the formulas of the chemicals involved. Many industry publications use common or alternative names for products. From the molecular formula provided, draw the structural formula. You will learn more about naming these compounds later in this chapter.

Table 3 Alberta Chemical Operations—Names and Formulas

Chemical	Alternative name(s)	Molecular formula
(a) ethane*	ethyl hydride	CH_3CH_3
(b) ethylene	ethene*	CH_2CH_2
(c) polyethylene	polyethene*	$(CH_2CH_2)_n$
(d) styrene	vinylbenzene* or phenylethene*	$CH_2CHC_6H_5$
(e) polystyrene	polyphenylethene* or Styrofoam®	$(CH_2CHC_6H_5)_n$
(f) vinyl chloride	chloroethene*	CH_2CHCl
(g) polyvinyl chloride	PVC, polychloroethene*, or polychloroethylene	$(CH_2CHCl)_n$
(h) ethylene glycol	ethane-1,2-diol* or 1,2-dihydroxyethane	CH_2OHCH_2OH
(i) ethylene dichloride	1,2-dichloroethane*	CH_2ClCH_2Cl

Note: The n is an indication that the structure repeats itself in a chain n units long. For this exercise, draw a full structural formula where $n = 3$.

*preferred (IUPAC) name

2. **Figure 3**, on the previous page, illustrates the job multiplier effect that results from creating ethene from ethane.

(a) For every 11 jobs in an ethene plant, how many potential jobs are created by using ethene?

(b) Alberta citizens and petrochemical companies have objected to the export of natural gas from which ethane has not been removed. Why?

(c) As the cost of natural gas increases, the value of ethane as a heating fuel increases. Consequently, the ethane may be burned as part of natural gas rather than being removed. How does burning ethane in natural gas affect the cost of ethane to petrochemical plants, the cost of products produced from ethene, and the number of jobs in the ethene industry?

3. Create a graph of your choice to communicate the relative quantities of petrochemicals produced in Canada (**Table 4**). Follow the link below to update the data from Statistics Canada.

Table 4 Petrochemical Production in Canada, 2004

Petrochemical	Production (Mt)
benzene	10
ethene (ethylene)	57
buta-1,3-diene	3
butenes (butylenes)	3
propene (propylene)	11
methylbenzene (toluene)	3
dimethylbenzenes (xylenes)	4
phenylethene (styrene)	9

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4. Use the information above and from your own research to continue gathering perspective statements concerning the statement that we should be saving more fossil fuels for petrochemical use in the future.

Organic Halides and Addition and Substitution Reactions 10.2

Chemists divide organic compounds into two main classes: hydrocarbons and hydrocarbon derivatives. As you learned in Chapter 9, hydrocarbons contain only carbon and hydrogen atoms. **Hydrocarbon derivatives** are molecular compounds of carbon, usually hydrogen, and at least one other element. (See the diagram of organic compound families in Chapter 9, **Figure 3** on page 382.) For ease of classification, such compounds are named as if they had been produced by the modification of a hydrocarbon molecule. The hydrocarbon-derivative families studied in this chapter are organic halides, alcohols, carboxylic acids, esters, and polymers.

Organic Halides

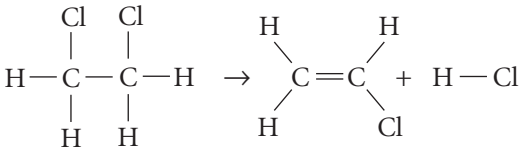
Organic halides are organic compounds in which one or more hydrogen atoms have been replaced by halogen (group 17) atoms. The functional group for organic halides is the halogen atom. A **functional group** is a characteristic arrangement of atoms within a molecule that determines the most important chemical and physical properties of a class of compounds. Organic halides include many common products, such as freons (chlorofluorocarbons) used in refrigerators and air conditioners, and Teflon® (polytetrafluoroethylene), used in cookware and labware.

Many organic halides are toxic and many are also carcinogenic, so their benefits must be balanced against potential hazards. Two such compounds are the insecticide DDT (dichlorodiphenyltrichloroethane) and PCBs (polychlorinated biphenyls), used in electrical transformers. PCBs are no longer being produced but are still in circulation. DDT is banned in many countries but is still being produced in some countries, such as China.

According to solution theory, organic halides are solvents that can dissolve nonpolar hydrocarbons and/or polar hydrocarbons. Organic halide molecules may be polar or nonpolar, or they may have a relatively nonpolar hydrocarbon end and a polar halide end.

IUPAC nomenclature for halides follows the same format as that for branched-chain hydrocarbons. The branch is named by shortening the halogen name to *fluoro-*, *chloro-*, *bromo-*, or *iodo-* (**Table 1**). For example, $CHCl_3(l)$ is trichloromethane (chloroform), an important solvent, and $C_6H_5Br(l)$ is bromobenzene, an additive to motor oils.

When translating IUPAC names for organic halides into full structural formulas, draw the parent chain and add branches at locations specified in the name. For example, 1,2-dichloroethane indicates that this compound has a two-carbon (eth-), single bonded parent chain (-ane), with one chlorine atom on each carbon (1,2-dichloro-). 1,2-dichloroethane is a liquid organic halide produced by Dow Chemical in Fort Saskatchewan. 1,2-dichloroethane is used to produce chloroethene, which in turn is used to produce polyvinyl chloride (PVC).



1,2-dichloroethane chloroethene

DID YOU KNOW?

Alkyl Halides

Organic halides are also known as alkyl halides and halogenated hydrocarbons. The term alkyl halides does not include aryl (aromatic) halides, such as bromobenzene. The more general term, organic halides, is used in this chapter.

Learning Tip

Each of the classes of hydrocarbon derivatives studied in this chapter is associated with a type of chemical reaction. For example,

- organic halides undergo addition and substitution reactions
- alcohols undergo elimination reactions
- carboxylic acids and esters are involved in esterification reactions

Try to use this organization to help you learn these concepts.

Table 1 Halide Functional Groups

Chemical symbol	Prefix
—F	fluoro
—Cl	chloro
—Br	bromo
—I	iodo

DID YOU KNOW?

Ozone Depletion

In 1982, a 30% decrease in the ozone layer—referred to as an ozone "hole"—was noticed for the first time by a team of British researchers working in Halley Bay, Antarctica. The British team's results surprised American researchers who had been measuring ozone levels by weather satellite since 1978. American satellite data are transmitted to Earth and are automatically processed by computers before scientists examine them. The Americans had not noticed the decrease in ozone levels because their computers were programmed to reject low measurements as invalid anomalies. The British scientists had also been monitoring atmospheric concentrations of chlorofluorocarbons (CFCs) and they raised the possibility that the decreasing ozone levels and the increasing CFC concentrations in the atmosphere were related. Since 1982, American computers processing total ozone mapping spectrophotometer (TOMS) data no longer reject low values, and alarming depletions of 60% to 70% in ozone levels over Antarctica have been detected.

The ozone layer has now stopped shrinking because of the measures we have taken to reduce our use of CFCs, but it will take many years to regenerate.

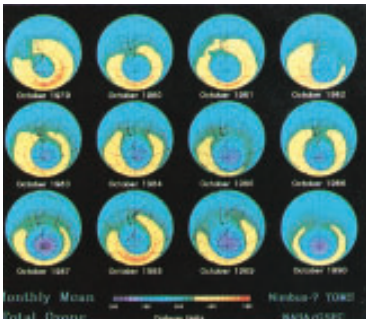


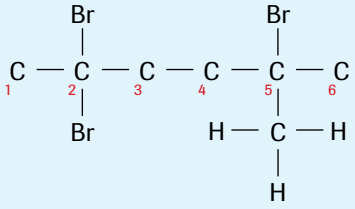
Figure 1
These NASA satellite photos show ozone levels over Antarctica as measured by the ozone-detecting device called TOMS. Look for recent photos on the Internet.

SAMPLE problem 10.1

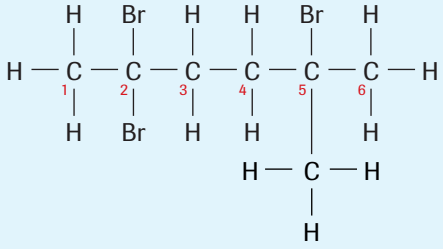
Draw a structural formula for 2,2,5-tribromo-5-methylhexane.

First, draw and number the parent alkane chain, the hexane:

Next, add two Br atoms to carbon 2, one Br atom to carbon 5, and a methyl group to carbon 5.

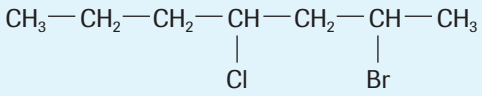


Finally, complete the bonding by adding H atoms to the C atoms.



COMMUNICATION example 1

Write the IUPAC name for the organic halide



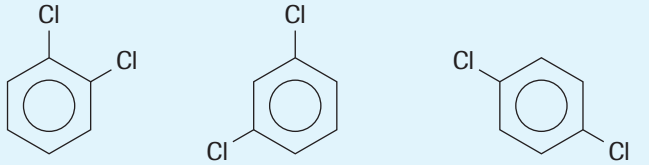
Solution

This compound is 2-bromo-4-chloroheptane.

COMMUNICATION example 2

Draw line structural formulas for the three isomers of dichlorobenzene. Name the isomers.

Solution



1,2-dichlorobenzene 1,3-dichlorobenzene 1,4-dichlorobenzene

Practice

1. Draw a structural formula for each of the following organic halides:
   (a) 1,2-dichloroethane (solvent for rubber)
   (b) tetrafluoroethene (used in the manufacture of Teflon)
   (c) 1,2-dichloro-1,1,2,2-tetrafluoroethane (refrigerant)
   (d) 1,4-dichlorobenzene (moth repellent)

2. Write IUPAC names for each of the formulas given.

(a) CHI_3 (antiseptic)

(b) $CH_2{=}C(CH_3){-}CH_2Cl$ (insecticide)

(c) CH_2Cl_2 (paint remover)

(d) $CH_2Br{-}CHBr{-}CH_2Br$ (soil fumigant)

(e) $C_6H_5Cl(l)$ (insoluble in water)

(f) $C_6H_5{-}CH{=}CH_2$ (monomer)

3. Use your knowledge of intermolecular forces to predict, with reasoning,

(a) the relative boiling points of ethene and chloroethene

(b) the relative solubility of ethene and chloroethene in water

4. Chlorofluorocarbons (CFCs) are organic halides that have chlorine or chlorine and fluorine atoms present. Until the 1990s, chlorofluorocarbons (CFCs) were used as refrigerants, foaming agents, and aerosol sprays. Besides depleting the ozone layer, CFCs are excellent absorbers of thermal infrared (IR) radiation; in other words, they are greenhouse gases (GHGs). Provide structural formulas for the following CFCs.

(a) $CCl_4(l)$

(b) $CH_3CCl_3(l)$

(c) $CFCl_3(l)$

(d) $CF_2ClCFCl_2(l)$

5. Hydrochlorofluorocarbons (HCFCs) have hydrogen and fluorine atoms present, in addition to chlorine atoms. HCFCs were used as a temporary replacement for CFCs in the 1990s. HFCs (hydrofluorocarbons) are replacing both CFCs and HCFCs. Draw structural formulas for these HCFCs.

(a) $CHF_2Cl(l)$

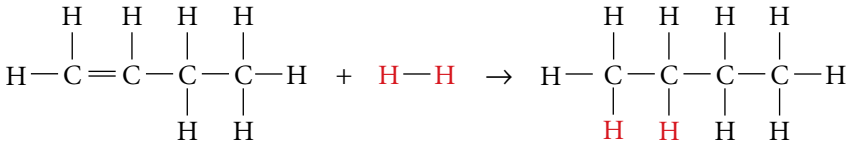
(b) $CH_3CFCl_2(l)$

(c) $CHF_3(l)$

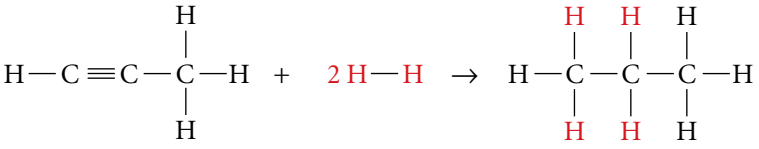
(d) $CF_3CH_2F(l)$

Addition Reactions

Unsaturated hydrocarbons react with small diatomic molecules, such as bromine and hydrogen. This type of reaction is an **addition reaction**. Addition reactions usually occur in the presence of a catalyst. Recall from Section 9.3 that addition of a sufficient quantity of hydrogen, called *hydrogenation*, converts unsaturated hydrocarbons to saturated ones. This reaction requires a catalyst.



but-1-ene + hydrogen → butane



propyne + excess hydrogen → propane

It seems logical that the addition of halogen or hydrogen halide molecules to the carbons of a double or triple bond would be an effective method of preparing halides. Experiment supports this expectation. Chemists explain the rapid rate of these reactions by the concept that a compound with a carbon–carbon double or triple bond can become more stable by achieving an octet of electrons in a tetrahedral structure of single bonds. For example, ethene reacts with chlorine, producing 1,2-dichloroethane. 1,2-dichloroethane is used as a solvent for fats, oils, and particularly for rubber. It is also

EXTENSION

CFCs, HFCs, and the Ozone Layer

As a result of Nobel Prize research on stratospheric ozone depletion by a group of chemists, CFCs were phased out of production, worldwide. Find out what the CFCs were being used for, and what follow-up agreements are in the works.

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Learning Tip

Recall that, for IUPAC nomenclature of substitution groups on a hydrocarbon chain, list the substituents in alphabetical order; e.g., 2-bromo-4-chloroheptane (as in Communication Example 1).

EXTENSION

Reactions of Hydrocarbons with Bromine

Watch a video in which bromine, dissolved in an inert solvent, is added to pentane and pent-1-ene in two dishes. Do these two hydrocarbons react in the same way?

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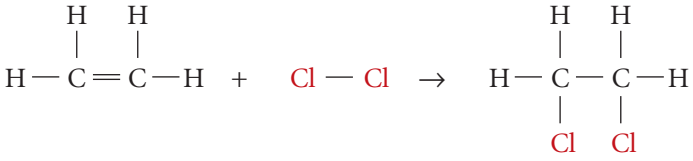
DID YOU KNOW?

Ethylene Dichloride

Why is ethylene dichloride the classical name for 1,2-dichoroethane? You can, perhaps, see the reason in the reaction equation for the production of 1,2-dichloroethane. Ethylene dichloride is produced from ethylene—it is a dichloride from (not of) ethylene. The name, ethylene dichloride, is misleading, which is why its IUPAC name is 1,2-dichloroethane.

used as a fumigant. More importantly for the Alberta chemical industry, 1,2-dichloroethane is used in huge quantities to produce chloroethene, a monomer used to produce the polymer PVC. (See the last equation on page 417 for the next step.)



ethene + chlorine → 1,2-dichloroethane

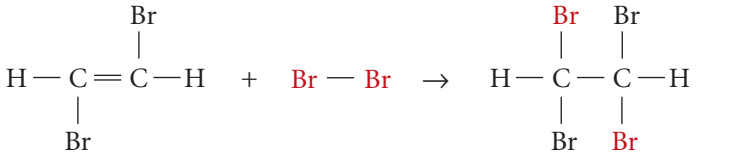
The addition of halogens to alkynes results in alkenes or alkanes. For example, the initial reaction of ethyne with bromine produces 1,2-dibromoethene.

ethyne + bromine → 1,2-dibromoethene

Since addition reactions involving multiple bonds are very rapid, the alkene product, 1,2-dibromoethene, can easily undergo a second addition step to produce 1,1,2,2-tetrabromoethane. Excess bromine promotes this second step.

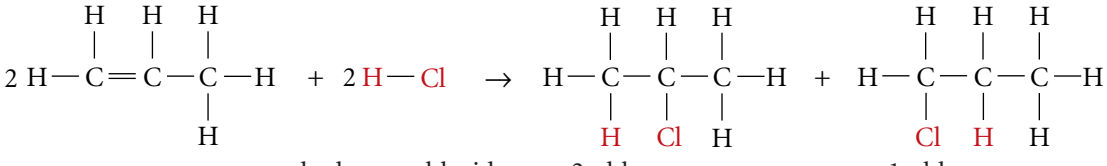
Learning Tip

The general formula for an organic halide is R — X, where X is a halogen atom, the functional group.



1,2-dibromoethene + bromine → 1,1,2,2-tetrabromoethane

The addition of hydrogen halides (HF, HCl, HBr, or HI) to unsaturated compounds can produce structural isomers, since the hydrogen halide molecules can add in different orientations. If you were to create the hypothesis that the addition might occur equally with orientations of H—Cl and Cl—H, then you would predict the following reaction.



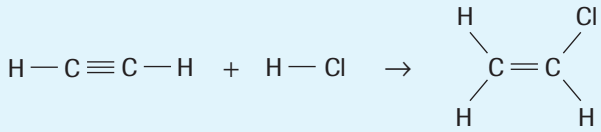
propene + hydrogen chloride → 2-chloropropane + 1-chloropropane

A laboratory test of this prediction would provide evidence to falsify this prediction. Only a tiny proportion of 1-chloropropane is produced compared to the 2-chloropropane.

COMMUNICATION example 3

Chloroethene (vinyl chloride) is made industrially in Alberta from a two-step reaction starting with ethene. An alternative method is to react ethyne (acetylene) with limited hydrogen chloride in the presence of a $HgCl_2$ catalyst. Write a structural formula equation to communicate this alternative reaction.

Solution

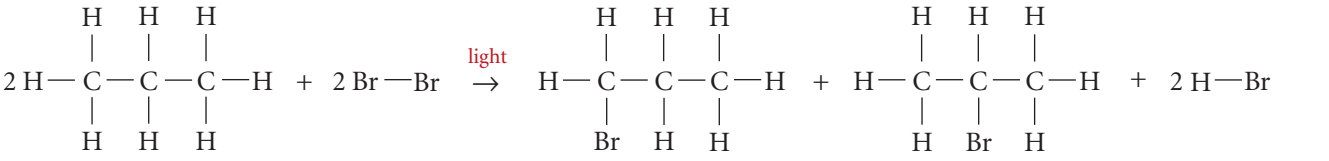


Substitution Reactions

According to laboratory work, another reaction that produces organic halides is a **substitution reaction**. The theoretical description of substitution reactions is that they involve breaking a carbon–hydrogen bond in an alkane or aromatic ring and replacing the hydrogen atom with another atom or group of atoms. These reactions often occur slowly at room temperature, indicating that very few of the molecular collisions at room temperature are energetic enough to break carbon–hydrogen bonds. Electromagnetic radiation (light) may be necessary for the substitution reaction to proceed at a noticeable rate. Consider the following example, the reaction of propane with bromine vapour:

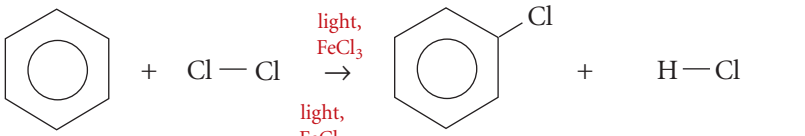
$$C_3H_8(g) + Br_2(g) \xrightarrow{\text{light}} C_3H_7Br(l) + HBr(g)$$

In this reaction, a hydrogen atom on the propane molecule is substituted with a bromine atom. Propane contains hydrogen atoms bonded in two different locations—those on an end-carbon atom and those on the middle-carbon atom—so two different products are formed, in unequal proportions. (The following reaction equation does not accurately represent this.)



propane + bromine $\xrightarrow{\text{light}}$ 1-bromopropane + 2-bromopropane + hydrogen bromide

Laboratory evidence indicates that benzene rings are stable structures and, like alkanes, react slowly with halogens, even in the presence of light. For example, the reaction of benzene with chlorine is shown to produce chlorobenzene and hydrogen chloride. As with alkanes, further substitution can occur in benzene rings until all hydrogen atoms are replaced by halogen atoms in the presence of excess halogens.



benzene + chlorine $\xrightarrow{\text{light, } FeCl_3}$ chlorobenzene + hydrogen chloride

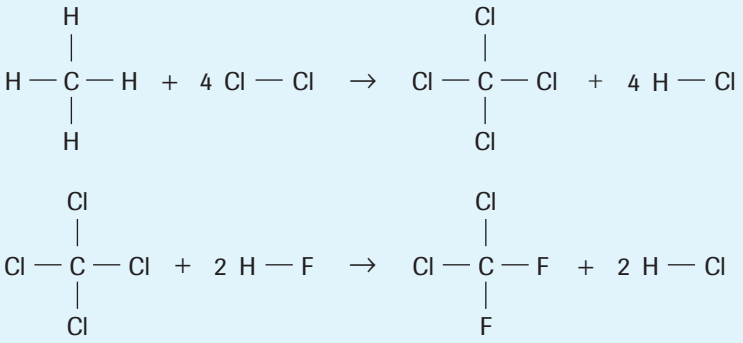
The reaction of benzene and chlorine is so slow that it requires light and a catalyst such as $FeCl_3$. This reaction produces HCl, as evidenced by wet blue litmus turning red

in or above the reaction mixture. This evidence dictates the reaction equation given above, and leads to the interpretation that this reaction is a substitution reaction.

COMMUNICATION example 4

CFCs were used until the 1990s as refrigerants (for refrigerators and air conditioners) and to create bubbles in plastic foams (used as foam insulation, foam trays, and cartons). CFC-12, which is pure CF_2Cl_2, was made by reacting carbon tetrachloride with gaseous hydrogen fluoride. The carbon tetrachloride was produced by reacting methane with chlorine. Draw structural formula equations to represent these two reactions.

Solution



INVESTIGATION 10.1 *Introduction*

Substitution and Addition Reactions

Substitution and addition reactions are two common classes of organic reactions. Substitution reactions are common to saturated hydrocarbons. Addition reactions are common to unsaturated (alkene and alkyne) hydrocarbons. In general, substitution reactions are slower and addition reactions are faster.

Purpose

The purpose of this investigation is to test the generalization that addition reactions are faster than substitution reactions.

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	● Evaluation (1, 2, 3)
○ Hypothesis	○ Procedure	
● Prediction	● Evidence	

Problem

Which compound reacts faster with aqueous bromine: cyclohexane or cyclohexene?

Design

Aqueous bromine is added to samples of cyclohexane and cyclohexene in both the presence and absence of light.

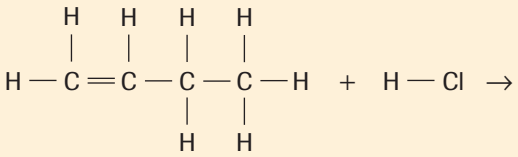
To perform this investigation, turn to page 461.

Practice

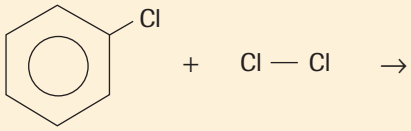
6. The halide derivatives of hydrocarbons form a wide variety of useful products. Draw structural formulas for the following examples:
(a) 1,2-dimethylbenzene (solvent) (b) 1,1,1-trichloroethane (a banned CFC)

7. Classify each of the following reactions as substitution or addition reactions. Predict all possible products for only the initial reaction. Complete the word equation and the structural formula equation in each case. Assume that light is present in all cases and catalysts are used as required.
(a) trichloromethane + chlorine →
(b) propene + bromine →
(c) ethylene + hydrogen iodide →
(d) ethane + chlorine →
(e) Cl — C ≡ C — Cl + F — F (excess) →

(f)



(g)



8. Classify and write balanced full structural formula equations for each of the following organic reactions. Assume that light is present in all cases and catalysts are used as required.
(a) propane + chlorine →
1-chloropropane + 2-chloropropane + hydrogen chloride
(b) propene + bromine → 1,2-dibromopropane
(c) benzene + iodine → iodobenzene + hydrogen iodide
(d) but-2-ene + hydrogen chloride → 2-chlorobutane
(e) bromobenzene + chlorine →

9. The synthesis of an organic compound typically involves a series of reactions, for example, some substitutions and some additions.
(a) Design an experiment beginning with a hydrocarbon to prepare 1,1,2-trichloroethane.
(b) Why do chemists and chemical engineers invent chemical processes?
(c) What other perspectives, besides scientific and technological, can be taken into account when inventing a new technology?

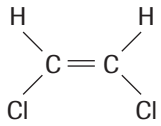
10. Test the explanatory power of intermolecular force theory by explaining why the two organic halide isomers, 1-bromopropane and 2-bromopropane, have different boiling points: 71 °C and 59 °C, respectively.

11. Petrochemicals are chemicals produced from petroleum (assume hydrocarbons) and from other petrochemicals, such as organic halides. Use your list of perspectives to classify the following statements about petrochemicals. (See STS Problem Solving in Appendix D.)
(a) Many human lives have been saved by the use of organic halide pesticides.
(b) Organic halides are used successfully as refrigerants and foaming agents.
(c) Research is on-going to find a replacement for CFCs and HCFCs.
(d) Farmers have saved considerable money by using organic halide pesticides.
(e) Getting elected may depend on promising that controls will be placed on the use of organic halides.
(f) There is a need for laws to control the release of organic halides.
(g) There are claims that workers in the past were not informed about the toxic or carcinogenic character of organic halides with which they worked.
(h) Communities have acted together to recycle petrochemical products.

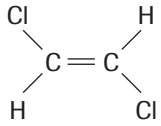
DID YOU KNOW?

Cis and *Trans* Isomerism

There is always a new concept to learn that extends what you have already learned. This applies to research chemists as much as it applies to you as a student. One example for you at this point is the introduction of evidence for the existence of *cis* and *trans* isomers, in addition to the structural isomers that you know about. Examples of *cis* and *trans* isomers are 1,2-dichloroethene, shown below as structural formulas.



cis-1,2-dichloroethene



trans-1,2-dichloroethene

Cis isomers involve special bonding on the same side of the double bond. *Trans* isomers have the special bonding across the double bond. See more on *cis* and *trans* isomerism in relation to transfats in Sections 10.4 and 10.5.

LAB EXERCISE 10.A

Synthesis of an Organic Halide

1,2-dichloroethane is also commonly called ethylene dichloride. Chemical engineers have invented ways to convert ethane to ethene to 1,2-dichloroethane to chloroethene to the plastic PVC (polyvinylchloride). Finding economically and environmentally sound ways to manufacture chemicals is the task of chemists and chemical engineers. Your task is to propose a reaction series for at least two different ways to manufacture 1,2-dichloroethane (ethylene dichloride) from hydrocarbons.

Report Checklist

● Purpose	○ Design	○ Analysis
● Problem	○ Materials	○ Evaluation
● Hypothesis	○ Procedure	
○ Prediction	○ Evidence	

SUMMARY Organic Halides

Properties

Organic halides

- may be polar or nonpolar molecules or may have a relatively nonpolar (hydrocarbon) end and a polar (halide) end
- have higher boiling points than similar hydrocarbons
- have very low solubility in water but higher solubility (especially for small molecules) than similar hydrocarbons
- are typically good solvents for organic materials such as fats, oils, waxes, gums, resins, and/or rubber

Preparation

- Addition reactions with halogens or hydrogen halides
  alkenes and alkynes $\rightarrow$ organic halides
  e.g., $CH_2{=}CH_2 + Cl_2 \rightarrow CH_2Cl{-}CH_2Cl$
- Substitution reactions with halogens
  alkanes and aromatics $\xrightarrow{\text{light}}$ organic halides
  e.g., $CH_3{-}CH_2Cl + Cl_2 \xrightarrow{\text{light}} CH_2Cl{-}CH_2Cl + H{-}Cl$

Section 10.2 Questions

1. Addition and substitution reactions typically require catalysts to produce a reasonable rate of reaction in a chemical plant. Substitution reactions occur (slowly) in the laboratory due to the presence of light. Design an experiment to test the last statement.
2. Organic halides include alkyl halides and halogenated hydrocarbons. Draw line structural formulas for the following organic halides.
   (a) 1,4-dichlorobenzene (moth repellant)
   (b) 1-bromo-4-methylbenzene (chemical reagent)
   (c) 1,2-dibromoethane (suspected carcinogen)
   (d) chloroethene (to produce PVC)
3. The relative boiling points of three halogen substituted ethane compounds are:
   chloroethane: 12.3 °C
   bromoethane: 38.2 °C
   iodoethane: 72.3 °C
   (a) Explain the relative boiling points of these organic halides.
   (b) Predict whether these compounds are more soluble in water or in ethanol.
4. Classify and write full structural formula equations for the following organic reactions:
   (a) propane + chlorine $\rightarrow$ 1-chloropropane + 2-chloropropane + hydrogen chloride
   (b) propene + bromine $\rightarrow$ 1,2-dibromopropane
   (c) benzene + iodine $\rightarrow$ iodobenzene + hydrogen iodide

Extension

5. Shortly after the connection was made between the "hole" in the ozone layer and the release of chlorofluorocarbons, many manufacturers stopped using CFCs as propellants in aerosol cans.
   (a) Research what alternatives were developed, and the effectiveness of each in the marketplace. Are the alternatives still in use? Have any of them been found to cause problems?
   (b) Design a product (one that must be sprayed under pressure) and its packaging. Plan a marketing strategy that highlights the way in which your product is sprayed from the container.

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6. Use the information in this section and from your own research to continue gathering perspective statements concerning the statement that we should be saving more fossil fuels for petrochemical use in the future.
7. Long-term replacements for CFCs and HCFCs include hydrofluorocarbons (HFCs), which have no chlorine atoms. HFCs are now being used in refrigerators, automobile air conditioners, aerosol cans, and as foaming agents. Draw the structural formula for CH_2FCF_3(l) (also called HFC-134a).
8. Why are some organic halides toxic whereas others are not? And why are some organisms affected more than others? Find out, using the following key words: bioaccumulation, fat soluble, food chain. Report on your findings in a short article for a popular science magazine or Web site.

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Alcohols and Elimination Reactions 10.3

Alcohols

Alcohols have many consumer, commercial, and industrial applications. They have very different properties compared to their hydrocarbon cousins with the same number of carbon atoms, such as relatively high solubility in water and clean burning properties. Chemists first classified alcohols by their empirical properties and their empirically determined formulas. Laboratory work showed that **alcohols** all contain one or more **hydroxyl groups**, –OH. The –OH group is the functional group for alcohols.

Alcohols have characteristic empirical properties that can be explained theoretically by the presence of a hydroxyl (–OH) functional group attached to a hydrocarbon chain. Alcohols boil at much higher temperatures than do hydrocarbons of comparable molar mass. Chemists explain that alcohol molecules, because of the –OH functional group, form hydrogen bonds (see Section 3.4, page 111) and, thus, liquid alcohols are less volatile than similar hydrocarbons. Shorter-chain alcohols are very soluble in water because of their size, polarity, and hydrogen bonding.

Because the hydrocarbon portion of the molecule of long-chain alcohols is non-polar, larger alcohols are less soluble in water and are good solvents for non-polar molecular compounds as well. (See the Solubility in Water Generalizations, Chapter 5, page 222.) Alcohols are frequently used as solvents in organic reactions because they are effective for both polar and non-polar compounds. Alcohols are also used as starting materials in the synthesis of other organic compounds.

Methanol and Ethanol

Two of the most common alcohols are methanol, $CH_3OH(l)$, and ethanol, $C_2H_5OH(l)$. Increasingly, one of the most important technological applications of alcohols is as a gasoline additive. Alcohol is added to gasoline in some jurisdictions, such as Manitoba, to increase the octane number, reduce harmful emissions (such as carbon monoxide), and conserve crude oil (see Chapter 9, page 399). The alcohols typically added are ethanol and methanol. These alcohols (as pure substances) have octane numbers of 113 and 108, respectively. They are often called oxygenators because they provide oxygen to the combustion reaction. The result is that less carbon monoxide is released in the exhaust. The combustion reaction of gasoline is, therefore, more complete.

An old method for manufacturing methanol involved decomposing and distilling the cellulose in wood, which is how it got its alternative name: wood alcohol. The modern method of preparing methanol involves two major processes. First, methane reacts catalytically with water (steam) to produce carbon monoxide and hydrogen:

$$CH_4(g) + H_2O(g) \xrightarrow{\text{catalyst}} CO(g) + 3\,H_2(g)$$

Next, carbon monoxide and hydrogen react at high temperature and pressure in the presence of a catalyst:

$$CO(g) + 2\,H_2(g) \xrightarrow{\text{catalyst}} CH_3OH(l)$$

A common consumer use of alcohols (including methanol) is as antifreezes (**Figure 2** on the next page).

Methanol is toxic to humans. Drinking even small amounts of it or inhaling the vapour for prolonged periods can lead to blindness or death. All alcohols are not the same. Methanol is even added to non-beverage ethanol to denature it. Denatured ethanol is toxic.

DID YOU KNOW ?

Ethanol in Alberta

At the time of writing, there are only three chemical plants in Alberta that produce ethanol from grain. The API Grain Processing Plant in Red Deer, Alberta produces industrial alcohol and Highwood Distillers in High River, Alberta produces beverage alcohol. There is also a large plant near the Alberta–Saskatchewan border at Lloydminster. In future, there will likely be more and more ethanol plants in western Canada to supply this gasoline additive. Grain-based ethanol plants are adding another significant market for grain farmers (**Figure 1**).

Figure 1
Grain is a source of ethanol, used as a gasoline additive to reduce GHG emissions.

Learning Tip

The general formula for an alcohol is R–OH. The alcohol functional group is the –OH (hydroxyl) group.

Figure 2
Alcohols available to consumers as antifreezes include, from left to right, gas line antifreeze (methanol), windshield de-icer (methanol), windshield washer antifreeze (methanol), and radiator and recreation vehicle antifreezes (ethane-1,2-diol and propane-1,2-diol).

Ethanol can be prepared by the fermentation of sugars from starch, such as corn and grains; hence its alternative name—grain alcohol. In the fermentation process, enzymes produced by yeast cells act as catalysts in the breakdown of sugar (glucose) molecules:

$$\text{starch} \rightarrow \text{glucose} \rightarrow \text{ethanol}$$

$$(C_6H_{10}O_5)_n(aq) \xrightarrow{\text{yeast}} C_6H_{12}O_6(aq) \rightarrow 2\,CO_2(g) + 2\,C_2H_5OH(aq)$$

In terms of industrial applications, ethanol is an important synthetic organic chemical. It is a solvent in lacquers, varnishes, perfumes, and flavourings, and is a raw material in the synthesis of other organic compounds.

Some oil companies in Alberta put ethanol in gasoline, for example, as a winter additive, for increased vaporization, and as a gas line antifreeze. Currently there is no legislation requiring ethanol in gasoline in Alberta.

There is an increasing number of ethanol plants being built in western Canada to produce ethanol as a gasoline additive. Provincial legislation to include 10% ethanol in gasoline, and tax incentives, will accelerate the expansion of the ethanol industry.

DID YOU KNOW ?

Fill Up with Methanol

Alcohols have many uses, one of the more recent being a fuel for motor vehicles. The problem with methanol as a pure fuel for cars is that it is less volatile than the hydrocarbons that make up gasoline, and the low volatility makes it difficult to ignite. In our cold Canadian winters, there is little methanol vapour in the engine and an electrical spark is insufficient to start the car. Canadian scientists are investigating a variety of dual ignition systems, one of which is a plasma jet igniter that is 100 times more energetic than conventional ignition systems.

Practice

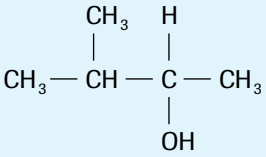
1. Chemical engineers have introduced alcohol into gasoline to play multiple roles. Describe at least three of these roles.
2. Write pro and con statements from social, political, and economic perspectives relative to the resolution that legislation should require the addition of alcohol to gasoline (gasohol) in Alberta.
3. Write the chemical equations for
   (a) photosynthesis to produce glucose
   (b) the conversion of glucose to starch
   (c) the fermentation of starch to glucose
   (d) the fermentation of glucose to ethanol
4. Volatile compounds evaporate or vaporize relatively easily. Volatile organic compounds (VOCs) can cause atmospheric smog. For molecules of the same molar mass, list hydrocarbons, organic halides, and alcohols, in general, in order of increasing volatility.

Naming Alcohols

Simple alcohols are named from the alkane of the parent chain. The *-e* is dropped from the end of the alkane name and is replaced with *-ol*. For example, the simplest alcohol, with one carbon atom, has the IUPAC name "methanol." The number of carbon atoms in the alcohol is communicated by the standard prefixes: *meth-*, *eth-*, *prop-*, etc. Single bonds between the carbon atoms are communicated by the "an" in the middle of the name, for example, ethanol rather than ethenol.

SAMPLE problem 10.2

Write the IUPAC name for the following alcohol.



1. Identify the longest continuous carbon chain on which the alcohol functional group—the hydroxyl (–OH) group—is located; e.g., four carbon atoms.
2. Write the prefix for the name to indicate the number of carbons in the longest chain; e.g., "but" for a four-carbon chain.
3. Add an "an" to the prefix to indicate that all of the carbon–carbon bonds are single bonds; e.g., "butan-".
4. Number the carbon chain from the end nearest the hydroxyl group; e.g., 1–4 from the right (in this case).
5. If necessary, add the locant (number) for the hydroxyl group to the name; e.g., "butan-2".
6. Complete the parent name with "-ol" to indicate that the compound is an alcohol; e.g., "butan-2-ol".
7. Indicate the presence of any substituent as a prefix; e.g., "methylbutan-2-ol".
8. If necessary, add the locant (number) to indicate the location of the substituent; e.g., "3-methylbutan-2-ol".
9. Double-check to make sure that the numbers are necessary to differentiate this compound from a similar compound; e.g., 2-methyl-1-butanol.

The name of this alcohol is 3-methylbutan-2-ol.

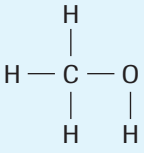
COMMUNICATION example 1

Due to their physical and chemical properties, alcohols have many technological applications. Provide the molecular and structural formulas for alcohols (a) and (b), and the molecular and condensed formulas for alcohols (c) and (d).

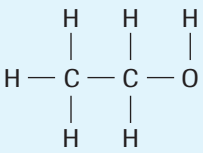
(a) methanol (race car fuel)
(b) ethanol (gasoline additive)
(c) propan-1-ol (solvent for organic compounds)
(d) butan-1-ol (used for manufacturing rayon)

Solution

(a) methanol: $CH_3OH(l)$



(b) ethanol: $C_2H_5OH(l)$



(c) propan-1-ol: $C_3H_7OH(l)$

$CH_3—CH_2—CH_2—OH$

(d) butan-1-ol: $C_4H_9OH(l)$

$CH_3—(CH_2)_3—OH$

Learning Tip

The nomenclature of alcohols is very similar to that of alkanes and alkenes. Look for the longest continuous chain, including the functional group in the case of alkenes and alcohols. Identify the location of any functional group and any substituent(s). Communicate all of this information in the format specified by IUPAC. For example,

- 2-methylbutane
- 2-methylbut-2-ene
- 2-methylbutan-2-ol

Try drawing the structural formula for each of the above compounds.

Learning Tip

The carbon atoms can be numbered from either end of the chain, whichever gives a lower number for the location of the hydroxyl group.

DID YOU KNOW ?

Alcohol Poisoning

Like other short-chain alcohols, ethanol is poisonous, and a concentration of only 0.40% in the blood can cause death. According to Canadian law, individuals whose blood alcohol levels are greater than 0.08% are considered impaired. Driving while impaired is a serious threat to the driver, the passengers, and anyone else on or near the road.

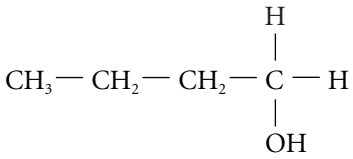
Primary, Secondary, and Tertiary Alcohols

By convention, when we write the molecular formula or the condensed structural formula (rather than the structural formula) for alcohols, we write the –OH group at the end, for example, C_2H_5OH or $CH_3 — CH_2 — OH$ for ethanol.

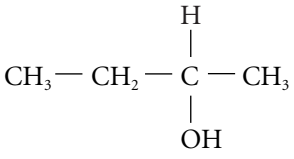
The position of the –OH group can vary, however, and make alcohols quite different, in terms of their chemical and physical properties. For example, the 1 in propan-1-ol indicates that the hydroxyl group is bonded to a carbon atom at the end of the carbon chain, that is, $CH_3CH_2CH_2OH(l)$ rather than $CH_3CHOHCH_3(l)$.

Structural models of alcohols with four or more carbon atoms suggest that three structural types of alcohols exist.

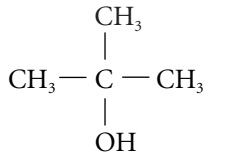
- *primary* (1°) *alcohols*, in which the carbon atom carrying the –OH group is bonded to one other carbon atom, as in $CH_3CH_2CH_2CH_2OH(l)$, butan-1-ol
- *secondary* (2°) *alcohols*, in which the carbon atom carrying the –OH group is bonded to two other carbon atoms, as in $CH_3CHOHCH_2CH_3(l)$, butan-2-ol
- *tertiary* (3°) *alcohols*, in which the carbon atom carrying the –OH group is bonded to three other carbon atoms, as in $(CH_3)_3COH(l)$, 2-methylpropan-2-ol



butan-1-ol,
a 1° alcohol



butan-2-ol,
a 2° alcohol

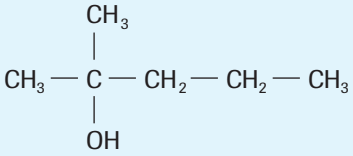


methylpropan-2-ol,
a 3° alcohol

When naming alcohols with more than two carbon atoms, we indicate the position of the hydroxyl group. For example, there are two isomers of propanol, C_3H_7OH: propan-1-ol is used as a solvent for lacquers and waxes, as a brake fluid, and in the manufacture of propanoic acid; propan-2-ol, or isopropanol, is sold as rubbing alcohol and is used to manufacture oils, gums, and acetone. (The prefix *iso-* indicates that the hydroxyl group is bonded to the central carbon atom.) Both isomers of propanol are toxic to humans if taken internally.

SAMPLE problem 10.3

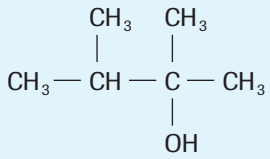
Name the following alcohol from its condensed structural formula and indicate whether it is a primary, secondary, or tertiary alcohol.



1. Identify the longest C chain. Since it is five Cs long, the alcohol is a pentanol.
2. Look at where the hydroxyl groups are attached. An −OH group is located on the second C atom, so the alcohol is a pentan-2-ol.
3. Look to see where any other group(s) are attached. A methyl group is located on the second C atom, so the alcohol is 2-methylpentan-2-ol.
4. Since the second C atom, to which the OH is attached, is attached to three other carbon atoms, the alcohol is a tertiary alcohol.

COMMUNICATION example 2

The following alcohol is used as a toxic denaturant for ethanol, as an octane booster in gasoline, as a paint remover, and for manufacturing perfumes. Name this alcohol from its condensed structural formula.

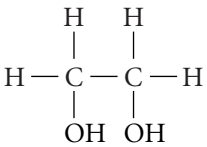


Solution

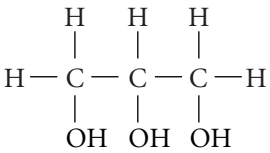
This tertiary alcohol is 2,3-dimethylbutan-2-ol.

Polyalcohols

Alcohols that contain more than one hydroxyl group are called *polyalcohols*; their names indicate the number and positions of the hydroxyl groups. For example, ethane-1,2-diol (ethylene glycol) is used as antifreeze for car radiators. Propane-1,2,3-triol (glycerol) is safe to consume, in limited quantities. It is a base material in many cosmetics and functions as a moisturizer in foods such as chocolates. Glycerol, also called glycerin and glycerine, is sold in drugstores. Fats and oils are derived from glycerol.



ethane-1,2-diol
(ethylene glycol)



propane-1,2,3-triol
(glycerol)

DID YOU KNOW?

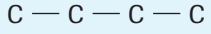
Glycerol: An Everyday Polyalcohol

The moisturizing effect of glycerol (propane-1,2,3-triol) is related to its multiple hydroxyl groups, each capable of hydrogen bonding with water molecules. When glycerol, commonly sold as glycerine in drugstores, is added to a soap bubble solution, the soap film formed contains more fixed water molecules and thus does not readily disintegrate from drying out (evaporation of water molecules).

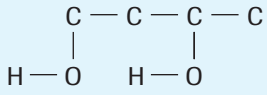
SAMPLE problem 10.4

Draw a structural formula for butane-1,3-diol.

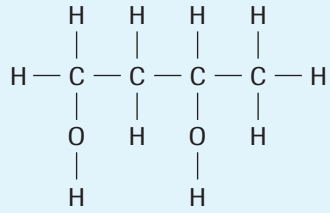
First, write the C skeleton for the parent molecule, butane.



Next, attach an OH group to the first and third C atoms.



Finally, complete the remaining C bonds with H atoms.



Learning Tip

Ask your teacher whether you will need to learn about cyclo-alcohols or aromatic alcohols. If so, ask about how complex the ones you need to know will be.

Cyclic and Aromatic Alcohols

Chemists have discovered alcohols whose parent compounds are cycloalkanes, cycloalkenes, and benzene. These compounds can become very complex quickly, so you only need to know some of the simplest examples:

- $C_6H_{11}OH(l)$ is cyclohexanol
- $C_6H_5OH(s)$ is phenol (an aromatic alcohol)

You may have heard of phenols when chemists talk about the odour and taste of spring run-off water. The phenols come from the decaying plant matter over which the water runs. Phenols are slightly soluble in water, more soluble in benzene, and very soluble in alcohols.

DID YOU KNOW ?

Grape Expectations

The cosmetics industry has developed a line of "anti-aging" creams that purport to make the skin look younger. The active ingredient is listed as polyphenols (extracted from grape seeds and skins (**Figure 3**), and also from olives). Manufacturers claim that these compounds, described as antioxidants, reverse signs of aging in the skin.

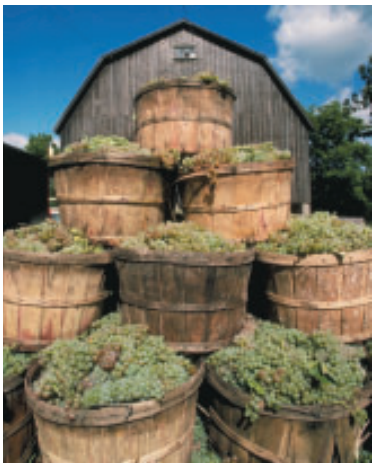
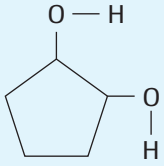


Figure 3
Grapes contain polyphenols—antioxidants that can be made into cosmetics.

COMMUNICATION example 3

Draw a line structural formula for cyclopentane-1,2-diol.

Solution



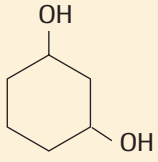
Practice

5. Write IUPAC names for the following compounds:

(a) $CH_3-\underset{\displaystyle OH}{\underset{|}{CH}}-CH_2-CH_3$

(b) $CH_3-\underset{\displaystyle OH}{\underset{|}{CH}}-CH_2-CH_2-CH_3$

(c)



6. Draw a structural formula for
(a) 3-methylbutan-1-ol
(b) methylpropan-2-ol
(c) cyclohexanol
(d) phenol

7. Draw line structural formulas and name:
(a) an isomer of butanol that is a secondary alcohol
(b) the isomers of $C_5H_{11}OH$ that are pentanols

8. Explain briefly why methanol has a higher boiling point than methane.

9. Predict the order of increasing boiling points for the following compounds, and give reasons for your answer.
(a) ethane, methanol, and fluoromethane
(b) butan-1-ol, pentane, and 1-chlorobutane

10. Glycerol is more viscous than water, and can lower the freezing point of water. When added to biological samples, it helps to keep the tissues from freezing, thereby reducing damage. From your knowledge of the molecular structure of glycerol, suggest reasons to account for these properties of glycerol.

11. Use your knowledge of intermolecular forces to predict, with reasoning,
(a) the relative boiling points of ethane, chloroethane, and ethanol.
(b) the relative solubility in water of ethane, chloroethane, and ethanol.

12. Methanol is produced from methane from natural gas in a two-step process. Write a molecular formula equation to communicate each of the following steps:
(a) Methane reacts with water to produce carbon monoxide and hydrogen.
(b) Carbon monoxide and hydrogen then react to produce methanol.

13. Ethanol can be produced by a two-step chemical process. Communicate the process using structural formula equations.
(a) Ethane from natural gas is cracked to produce ethene.
(b) Ethene reacts with water in an addition reaction to produce ethanol.

14. Only a few of the simpler alcohols are used in combustion reactions. Alcohol–gasoline mixtures, known as gasohol, are the most common examples. Write a balanced chemical equation, using structural formulas, for the complete combustion of each of the following alcohols:
(a) ethanol (in gasohol)
(b) methanol (in gas line antifreeze, **Figure 4**)

15. Ethanol is a beverage alcohol. Calculate the volume of ethanol in each of the drinks in (a), (b), and (c):
(a) 355 mL of beer (5.0% ethanol by volume)
(b) 150 mL of wine (12% ethanol by volume)
(c) 45 mL of rum (40% ethanol by volume)
(d) How does the quantity of ethanol compare for each of these standard-size drinks?

16. Why is industrial (and school) ethanol denatured (made toxic with, for example, methanol)? Include an economic and a societal perspective in your answer.

17. Alcohols have varying physical properties that may be attributed to intermolecular bonding. Test intermolecular bonding theories by predicting the relative boiling points of the alcohols listed below. Support your prediction with reasoning, based on intermolecular bonding theories. Collect the evidence from a named reference source such as the *CRC Handbook of Chemistry and Physics* or the Internet. Complete Step 2 of an Evaluation.

Purpose
The purpose of this investigation is to test intermolecular bonding theories.

Problem
What are the relative boiling points of butan-1-ol, methanol, propan-1-ol, and ethanol?

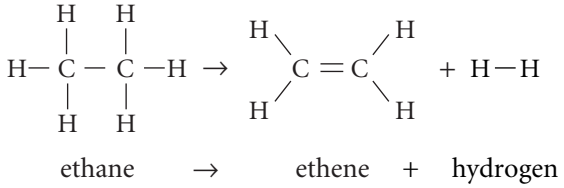
Figure 4
Methanol, sold as methyl hydrate, is used throughout Canada as gas line antifreeze and windshield washer fluid.

Elimination Reactions

The production of alkenes is a very important laboratory and industrial reaction. As you know from Section 10.1, ethene is the cornerstone of the Alberta petrochemical industry. As you will learn in Section 10.5, alkenes are necessary to produce one of the two main classes of polymers. Besides cracking reactions mentioned in Chapter 9 and reviewed below, elimination reactions are a primary source of alkenes—derived from either alcohols or alkyl halides.

Producing Ethene by Cracking Ethane

As indicated in Chapter 9, chemical engineers have devised several methods for producing ethene on an industrial scale. Over time, high-temperature cracking of ethane, as illustrated below, became the preferred technological process. As you can see, molecules of hydrogen are "eliminated" from the ethane.



Learning Tip

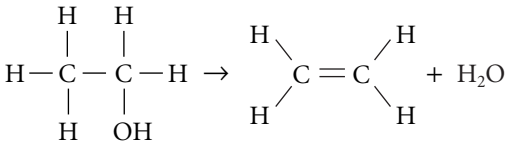
Recall that the ethane to ethene reaction is called cracking, although it is quite different from cracking that involves breaking carbon–carbon bonds. Sometimes tradition determines the name of something against usual reasoning. This process is also sometimes called elimination or dehydrogenation.

Figure 5
A gas generator produces ethene, which speeds the ripening of fruits such as bananas. Ethanol reacts in the gas generator in the presence of an acid catalyst—an elimination reaction.

In review, ethane is cracked into ethene in a world-scale plant at, for example, Joffre, east of Red Deer, Alberta. The ethane used in the cracking process in Alberta comes from natural gas.

Producing Ethene by Elimination Reactions

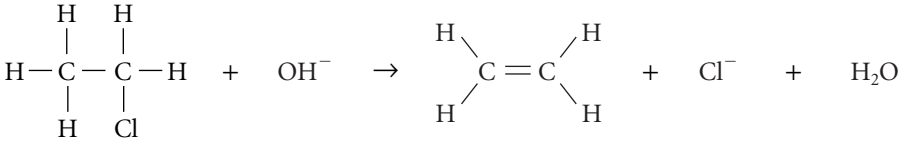
Ethene was discovered serendipitously in the 17th century by heating ethanol in the presence of sulfuric acid (as a catalyst). Eventually, chemists experimented with many catalysts other than sulfuric acid and found that aluminium oxide and phosphoric acid were effective in this reaction (**Figure 5**).



ethanol → ethene + water

This reaction, called an **elimination reaction**, involves eliminating atoms and/or groups of atoms from adjacent carbon atoms in an organic molecule. In the case of the synthesis of ethene from ethanol, a hydrogen atom and a hydroxyl group on adjacent carbon atoms are eliminated, forming water as a by-product. This particular kind of elimination reaction is also called *dehydration*, because of the apparent removal of water from the alcohol.

Another example of an elimination reaction is the dehydrohalogenation (removal of hydrogen and halogen atoms) of an organic halide to produce an alkene. Ethene can, for example, be produced in the laboratory by reacting chloroethane with potassium hydroxide:



chloroethane + hydroxide ion → ethene + chloride ion + water

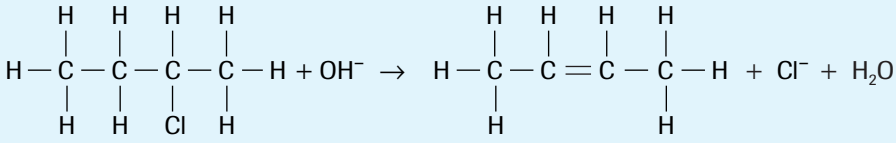
In this reaction, a hydrogen atom and a halogen atom are eliminated from the alkyl halide to produce the alkene plus a halide ion and a water molecule.

Chemists have identified other elimination reactions and other ways to synthesize ethene and other alkenes. Research has indicated, however, that the above two methods (starting with ethanol or chloroethane) are the best choices for the laboratory. From an industrial perspective, the cracking of abundant fossil fuel alkanes to produce alkenes is the preferred method.

COMMUNICATION example 4

The elimination of a halide ion from an organic halide is the most common method for preparing a specific alkene in the laboratory. Write a structural formula equation for the preparation of but-2-ene from 2-chlorobutane, in the presence of a strong base.

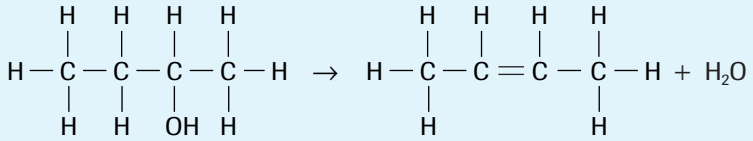
Solution



COMMUNICATION example 5

The elimination of the elements of a water molecule from an alcohol is the second most common method for preparing a specific alkene in the laboratory. Write a structural formula equation for the preparation of but-2-ene from butan-2-ol, in the presence of a catalyst.

Solution



Practice

18. Write a structural formula equation to represent the synthesis of ethene by reacting bromoethane with a strong base.

19. Alkenes can be manufactured by three different chemical processes. Write structural formula equations for each of the following hypothetical chemical processes:
(a) Butane is cracked into but-2-ene.
(b) 1-chlorobutane undergoes an elimination reaction in a strongly basic solution to produce but-1-ene, chloride ions, and water.
(c) butan-1-ol undergoes an elimination reaction to produce but-1-ene and water.

20. Write structural formula equations for the synthesis of propene by three different processes.

21. Chemical engineers face many difficulties during the technological design of ethane cracking plants (**Figure 6**). Suggest a different solution to each of the following problems encountered when ethane is thermally cracked:
(a) 40% of the ethane remains uncracked after coming from the ethane cracker
(b) ethyne (acetylene) is produced in addition to ethene
(c) hydrogen and methane are produced

Figure 6
Alberta is Canada's top producer of petrochemicals and home to the world's two largest ethane-based processing plants—at Joffre, east of Red Deer, and Fort Saskatchewan, northeast of Edmonton. This photo shows the largest of the three ethylene plants located at the Joffre site. Significant infrastructure supports the Joffre site facilities: feedstock pipelines, an ethane extraction plant, and a cogeneration power plant.

INVESTIGATION 10.2 *Introduction*

Isomers of Butanol

Organic halides have many uses, but they are not commonly found in nature. Organic halides must, therefore, be synthesized from other compounds. On an industrial scale, organic halides are produced by addition and substitution reactions of hydrocarbons. A common laboratory-scale process is the halogenation of alcohols in which the hydroxyl group of the alcohol is replaced by a halogen. This reaction requires the presence of a strong acid that contains a halogen, such as hydrochloric acid.

$$R\text{–}OH(l) + HX(aq) \rightarrow R\text{–}X(l) + H_2O(l)$$

Organic halides have much lower solubilities in water compared with their corresponding alcohols.

Purpose

The purpose of this investigation is to test a personal hypothesis about the relative reactivity of the alcohol isomers of butan-1-ol.

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	● Materials	● Evaluation (1, 2, 3)
● Hypothesis	○ Procedure	
● Prediction	● Evidence	

Problem

What is the difference in reactivity, if any, of the alcohol isomers of butan-1-ol with concentrated hydrochloric acid?

Design

Samples of butan-1-ol, butan-2-ol, and 2-methylpropan-2-ol are mixed with concentrated hydrochloric acid. Evidence of reaction is obtained by looking for a low-solubility organic halide product (cloudy mixture).

To perform this investigation, turn to page 462.

SUMMARY Alcohols and Elimination Reactions

Alcohols

Functional group:
–OH, hydroxyl group

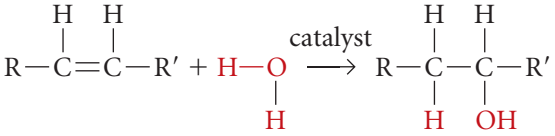
Naming alcohols:

- Drop the "e" from the alkane name and add "ol"; e.g., ethane becomes ethanol.
- If necessary, add a number (or numbers) to communicate where the hydroxyl group(s) is (are) located; e.g., propan-1-ol and propan-2-ol.
- If the alcohol has two or three hydroxyl groups, it is a diol or a triol, respectively; e.g., ethane-1,2-diol and propane-1,2,3-triol. For diols and triols, do not drop the "e" from the alkane name.

Preparation:

Addition reactions with water

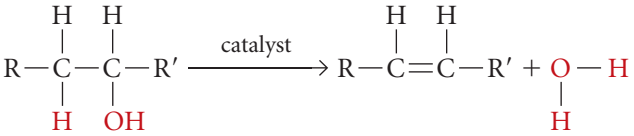
- alkenes + water → alcohols



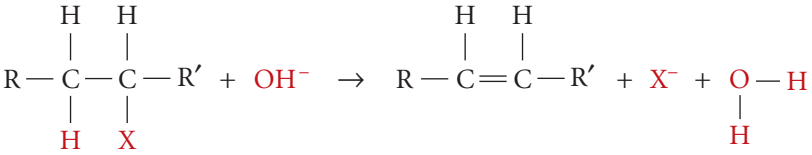
(R and R′ can be the same or different alkyl groups. Isomers often result.)

Elimination Reactions

- alcohols → alkenes + water



- organic halides + OH^- → alkenes + halide ion + water



Learning Tip

The types of organic reactions that you are responsible for learning to this point in the unit are:

1. photosynthesis and respiration
2. hydrocracking
3. catalytic reforming
4. complete and incomplete combustion
5. substitution
6. addition
7. elimination

WWW WEB Activity

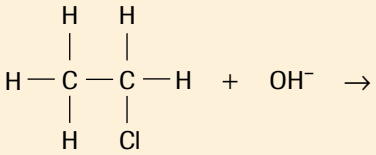
Web Quest—Cellulosic Ethanol

This Web Quest focuses on the technological, environmental, and ecological impacts of building a cellulosic ethanol plant. In the past, ethanol was widely used as a fuel, only to be replaced by abundant and inexpensive gasoline. What are the issues with creating and using cellulosic ethanol? Does it have the potential to provide a realistic alternative to gasoline? You will examine the cellulosic ethanol plant from the point of view of a consulting firm, and present your supported conclusions to the community.

www.science.nelson.com GO

Section 10.3 Questions

1. Write structural formulas and IUPAC names for all saturated alcohols with four carbon atoms and one hydroxyl group.
2. Explain why the propane that is used as fuel in a barbecue is a gas at room temperature, but propan-2-ol, used as rubbing alcohol, is a liquid at room temperature.
3. Draw the structural formulas and write the IUPAC names of the two alkenes that are formed when hexan-2-ol undergoes an elimination reaction in the presence of an acid catalyst.
4. Write an equation using structural formulas to show the production of each of the following alcohols from an appropriate alkene:
   (a) butan-2-ol (b) methylpropan-2-ol
5. A major use of organic halides is in the preparation of unsaturated compounds. Predict the products of the following elimination reaction. Write a word equation and a structural formula equation.



6. Classify and write structural formula equations for the following catalyzed organic reactions:
   (a) ethene + water → ethanol
   (b) butan-2-ol → but-1-ene + but-2-ene + water
   (c) ethene + hypochlorous acid (HOCl(aq)) → 2-chloroethanol
   (d) cyclohexanol + oxygen →
7. Draw structural formulas to represent the elimination reaction of 2-chloropentane to form an alkene. Include reactants, reaction conditions, and all possible products and their IUPAC names.
8. The nomenclature of organic compounds is similar across classes of compounds. Name the following alkanes, alkenes, and alcohols.
   (a) $CH_3—CH_2—CH_2—CH_3$
   (b) $CH_3—CH(CH_3)—CH_3$
   (c) $CH_3—CH=CH—CH_3$
   (d) $CH_3—C(CH_3)=CH_2$
   (e) $CH_3—CH_2—CH_2—CH_2—OH$
   (f) $CH_3—CH_2—CH(OH)—CH_3$
   (g) $CH_3—CH(CH_3)—CH_2—OH$
   (h) $CH_3—C(CH_3)(OH)—CH_3$
9. Draw line structural formulas for the following alcohols.
   (a) propan-2-ol
   (b) phenol (hydroxybenzene)
   (c) propane-1,2,3-triol (glycerol)
   (d) cyclohexanol
10. Complete the Hypothesis (including reasoning), Analysis, and Evaluation (2, 3) for the following investigation report:

Purpose

The purpose of this investigation is to test a hypothesis concerning the relative boiling points and solubility of alcohols. Assume that solubility means in water.

Problems

(a) What is the trend in boiling points for C_1–C_6 primary alcohols?
(b) What is the trend in solubility for C_1–C_6 primary alcohols?

Evidence

Table 1 Boiling Points and Solubilities of Various Alcohols

Alcohol	Boiling point (°C)	Solubility (mL/100 mL)
methanol	65	miscible
ethanol	78	miscible
propan-1-ol	97	miscible
butan-1-ol	117	9.1
pentan-1-ol	138	3.0
hexan-1-ol	157	slight

11. Use the information in this section and from your own research to continue gathering perspective statements concerning the statement that we should be saving more fossil fuels for petrochemical use in the future.

Extensions

12. Alcohols have gained increased popularity as an additive to gasoline, as a fuel for automobiles. "Gasohols" may contain up to 10% methanol and ethanol, and are considered more environmentally friendly than gasoline alone.
    (a) Write balanced chemical reaction equations for the complete combustion of methanol and ethanol.
    (b) When small amounts of water are present in the gasoline in the gas lines of a car, the water may freeze and block gasoline flow. Explain how using a gasohol would affect this problem.

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13. Radiator antifreeze and coolant is ethane-1,2-diol (ethylene glycol). Ethylene glycol is usually mixed 50:50 with water for use in the radiator. Large quantities of this chemical product are produced near Fort Saskatchewan and Scotford, Alberta. Ethene reacts with oxygen in one reactor to produce ethylene oxide ($C_2H_4O(g)$). The ethylene oxide then reacts with water in a second reactor to produce ethylene glycol.
    (a) Write structural formula equations for these reactions.
    (b) Explain why ethylene glycol is a better choice as a radiator antifreeze and coolant than ethanol.
    (c) Explain why methanol, rather than ethylene glycol, is used as a windshield wiper antifreeze.
    (d) Which is more toxic, methanol or ethylene glycol?
    (e) Use a reference to find the freezing point of a 50:50 mixture of ethylene glycol and water.

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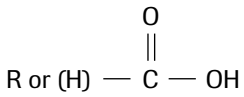
10.4 Carboxylic Acids, Esters, and Esterification Reactions

Learning Tip

The general formula for a carboxylic acid is

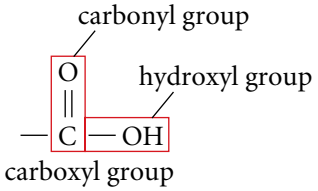


The functional group for carboxylic acids is the carboxyl group, –COOH.

Natural products and processes involve a wide variety of organic chemicals. In this section, you will learn what chemists and chemical engineers have discovered about some organic products and processes. Chemists, like you, started off learning the basics of organic chemistry—just as you have learned about inorganic chemistry. The study of most topics in science begins with classification based on the physical and chemical properties of the chemicals involved. Nomenclature—providing names for the classes of chemicals and for individual chemicals—usually follows quickly after the classification process. The parallel process is most often the creation of theories to explain the properties of each of the classes of compounds.

Carboxylic Acids

The family of organic compounds known as **carboxylic acids** contain the **carboxyl group**, –COOH, which includes both the carbonyl and hydroxyl functional groups.



Note that, because the carboxyl group involves three of the carbon atom's four bonds, the carboxyl group is always at the end of a carbon chain or branch.

Chemists explain the characteristic properties of carboxylic acids by the presence of the carboxyl group. Carboxylic acids occur naturally in citrus fruits, crabapples, rhubarb, and other foods characterized by the sour, tangy taste of acids. Carboxylic acids also have distinctive odours (**Figure 1**).

As we might predict from the structure of carboxylic acids, the molecules of these compounds are polar and form hydrogen bonds both with each other and with water molecules. These acids exhibit the same solubility behaviour as alcohols. The smaller members (one to four carbon atoms) of the acid series are miscible with water, whereas larger ones are virtually insoluble. Aqueous solutions of carboxylic acids have the properties of acids; a litmus test can distinguish these compounds from other hydrocarbon derivatives. The smaller carboxylic acids are all liquids at room temperature. The dicarboxylic acids (even the small ones) are solids at room temperature, as are the larger-molecule carboxylic acids.

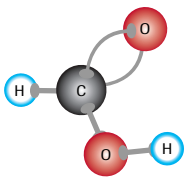
Carboxylic acids are named by replacing the *-e* ending of the corresponding alkane name with *-oic*, followed by the word "acid." The first member of the carboxylic acid family is methanoic acid, HCOOH, commonly called formic acid (**Figure 2**). Methanoic acid is used in removing hair from hides and in coagulating and recycling rubber.

Figure 1
Tracking dogs, with their acute sense of smell, are trained to identify odours in police work. As carboxylic acids have distinctive odours, the dogs may follow the characteristic blend of carboxylic acids in a person's sweat. Trained dogs are also used to seek out illegal drug laboratories by the odour of acetic acid. Acetic acid is formed as a byproduct when morphine, collected from opium poppies, is treated to produce heroin.

Figure 2
(a) Most ants and ant larvae are edible and are considered quite delicious. They have a vinegary taste because they contain methanoic acid, HCOOH, commonly called formic acid. In some countries, large ants are squeezed directly over a salad to add the tangy ant juice as a dressing.
(b) This ball-and-spring model represents the evidence chemists have collected on methanoic acid.

(a)

(b)

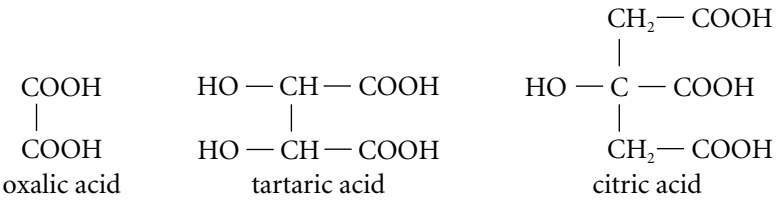


Ethanoic acid, $CH_3COOH(l)$, commonly called acetic acid, is the compound that makes vinegar taste sour (**Figure 3(a)**). Wine vinegar and cider vinegar are produced naturally when sugar in fruit juices is fermented first to alcohol, and then to ethanoic acid. This acid is employed extensively in the textile dyeing process and as a solvent for other organic compounds.

glucose $\rightarrow$ ethanol $\rightarrow$ ethanoic acid (acetic acid)

fruit juice $\rightarrow$ wine $\rightarrow$ vinegar

Some acids contain two or three carboxyl groups. For example, oxalic acid, used in commercial rust removers and in copper and brass cleaners, consists of two carboxyl groups bonded together. Oxalic acid (**Figure 3(b)**) occurs naturally in rhubarb, tartaric acid occurs in grapes, and citric acid occurs in citrus fruits. Due to the extra hydrogen bonding, all three of these acids are solids as pure substances at room temperature.



You do not have to memorize these names and condensed structural formulas, or those of any other polycarboxylic acids. However, you should recognize that they are carboxylic acids (from the carboxyl functional groups). You should also recognize that multiple hydrogen bonding is possible, which increases the melting and boiling points and solubility in water of these compounds.

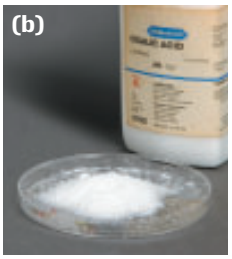


Figure 3
Oxalic acid (**b**), found in rhubarb, differs from pure acetic (ethanoic) acid, $CH_3COOH(l)$ (**a**), in that its molecule contains an additional carboxyl group. This increased polarity and hydrogen bonding explain why oxalic acid is a solid while pure acetic acid is a liquid at the same temperature.

LAB EXERCISE 10.B

Explaining Physical Property Trends

Many physical properties of organic compounds can be understood using knowledge of the functional groups present and of intermolecular forces. Complete the Analysis and Evaluation of the investigation report.

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	● Evaluation (3)
○ Hypothesis	○ Procedure	
○ Prediction	○ Evidence	

Purpose

The purpose of this investigation is to use your knowledge of organic structures and intermolecular forces to explain some physical properties of alcohols and carboxylic acids.

Problem

What is the explanation for the trends in boiling points and solubilities in water within and between series of simple alcohols and carboxylic acids?

Evidence

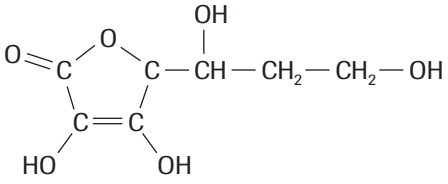
Table 1 Boiling Points and Solubilities of Various Alcohols and Carboxylic Acids

Alcohol	Boiling point (°C)	Solubility in water (g/100 mL)	Carboxylic acid	Boiling point (°C)	Solubility in water (g/100 mL)
methanol	65	miscible	methanoic acid	101	miscible
ethanol	79	miscible	ethanoic acid	118	miscible
propan-1-ol	97	miscible	propanoic acid	141	miscible
butan-1-ol	117	8.0	butanoic acid	164	miscible
pentan-1-ol	137	2.7	pentanoic acid	186	2.4

DID YOU KNOW ?

Water-Soluble Vitamins

With its many polar hydroxyl groups, vitamin C (ascorbic acid) is highly water-soluble. The water-soluble vitamins are not stored in the body; rather, they are readily excreted in the urine. It is, therefore, important that we include these vitamins in our daily diet. Although taking too much vitamin C is not dangerous, taking excessive amounts is truly sending money down the drain.



ascorbic acid
(Vitamin C)

Learning Tip

The technological applications of the following chemicals should be memorized as common knowledge:

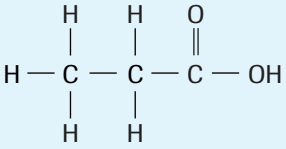
$CH_4(g)$	natural gas
$C_3H_8(g)$	barbecue fuel
$C_4H_{10}(g)$	lighter fluid
$C_8H_{18}(l)$	in gasoline
$C_2H_4(g)$	polyethylene monomer
$C_2H_2(g)$	cutting torch fuel
$C_6H_6(l)$	in gasoline
$CH_3OH(l)$	gasoline antifreeze
$C_2H_5OH(l)$	beverage alcohol
CH_2OHCH_2OH	radiator antifreeze
$CH_3COOH(l)$	in vinegar

SAMPLE problem 10.5

Write the IUPAC name and the full structural formula for propanoic acid.

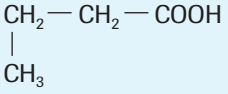
The prefix *propan-* indicates that the acid contains three C atoms; the end C atom is in the carboxyl group.

The structural formula for propanoic acid is



COMMUNICATION example 1

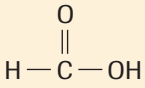
What is the IUPAC name for this carboxylic acid, which has an unpleasant, rancid odour?



Solution

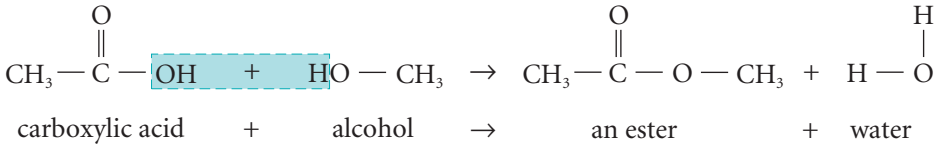
This condensed structural formula represents butanoic acid.

Practice

1. Draw a structural formula for each of the following compounds:
   (a) octanoic acid
   (b) benzoic acid
   (c) ethanoic (acetic) acid
2. Give IUPAC and, if applicable, common names for these molecules:
   (a) 
   (b) $HOOC-CH_2-CH_2-CH_2-CH_3$
   (c) $CH_3-CH_2-CH_2-CH_2-CH_2-COOH$

Esterification Reactions

Carboxylic acids undergo a variety of organic reactions. In a **condensation reaction**, a carboxylic acid combines with another reactant, forming two products—an organic compound and a compound such as water. For example, a carboxylic acid can react with an alcohol, forming an **ester** and water. This type of condensation reaction is known as an **esterification reaction**.



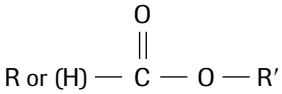
Esters

The **ester functional group**, –COO–, is similar to that of an acid, except that the hydrogen atom of the carboxyl group has been replaced by a hydrocarbon branch. Esters occur naturally in many plants and are responsible for some of the odours of fruits and flowers. Esters are often added to foods to enhance aroma and taste. Other commercial applications include cosmetics, perfumes, synthetic fibres, and solvents.

The odour of food strongly influences its flavour. Artificial flavourings are made by mixing synthetic esters to give the approximate odour (such as raspberry or banana) of the natural substance. For artificial fruit flavours, organic acids are usually added to give the sharp taste characteristic of fruit. Artificial flavours can only approximate the real thing, because it would be too costly to include all the components of the complex mixture of compounds present in the natural fruit or spice. **Table 2** shows the main esters used to create the odours of certain artificial flavours. The names are covered next.

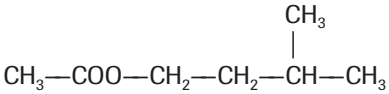
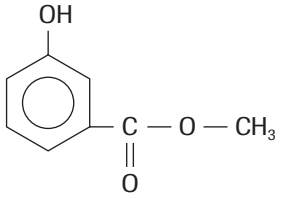
Learning Tip

The general formula for an ester is



where R′ is the branch from the alcohol and R (or H) is from the acid.

Table 2 Odours of Selected Esters

Odour	Name	Formula
apple	methyl butanoate	$CH_3—CH_2—CH_2—COO—CH_3$
apricot	pentyl butanoate	$CH_3—(CH_2)_2—COO—(CH_2)_4—CH_3$
banana	3-methylbutyl ethanoate	
cherry	ethyl benzoate	$C_6H_5—COO—CH_2—CH_3$
orange	octyl ethanoate	$CH_3—COO—(CH_2)_7—CH_3$
pineapple	ethyl butanoate	$CH_3—CH_2—CH_2—COO—CH_2—CH_3$
red grape	ethyl heptanoate	$CH_3—(CH_2)_5—COO—CH_2—CH_3$
rum	ethyl methanoate	$H—COO—CH_2—CH_3$
wintergreen	methyl salicylate	

Learning Tip

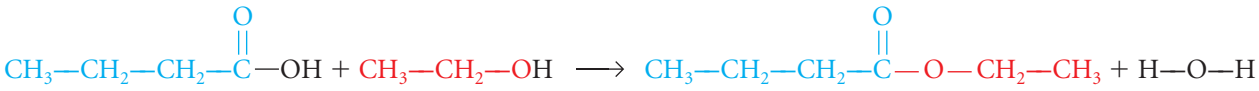
Note that the names for esters have a space between the prefix and the principal group, for example, ethyl butanoate. These "organic salts" are named like inorganic salts; e.g., sodium chloride.

Naming and Preparing Esters

Esters are organic "salts" formed from the reaction of a carboxylic acid and an alcohol. Consequently, the name of an ester has two parts. The first part is the name of the alkyl group from the alcohol used in the esterification reaction. The second part comes from the acid. The ending of the acid name is changed from *-oic* acid to *-oate*. For example, in the reaction of ethanol and butanoic acid, the ester formed is ethyl butan*oate*, an ester with a banana odour. A strong acid catalyst, such as $H_2SO_4(aq)$, is used to increase the rate of this organic reaction, along with some careful heating.

Learning Tip

Note the colour coding of the reactant segments that show the movement of the O atoms and that also assist with naming the ester.



butanoic acid + ethanol → ethyl butanoate + water

carboxylic acid + alcohol → ester + water

DID YOU KNOW?

Radioactive Tracing

Radioactive tracing can be used by medical personnel to trace the movement of chemicals in your body. Chemists use a similar approach to trace the movement of atoms in a chemical reaction. For example, if the O atom in propan-1-ol is manipulated to be radioactive (O-18), and the resulting ester is radioactive, then the radioactive O-18 atom has moved to the ester. The hydroxyl (—OH) group from the acid, therefore, must move to the water. Radioactive tracing is not important for predicting the products, but it provides chemists with deeper theoretical understanding.

The general formula of an ester is written as RCOOR′. When read from left to right, RCO– comes from the carboxylic acid, and –OR′ comes from the alcohol. Hence, $CH_3COOCH_2CH_2CH_3$ is propyl ethanoate. Note that, for an ester, the acid is the first part of its formula as drawn, but is the second part of its name.

$$C_3H_7COOH + CH_3OH \rightarrow C_3H_7COOCH_3 + H_2O$$

butanoic acid methanol methyl butanoate

SAMPLE problem 10.6

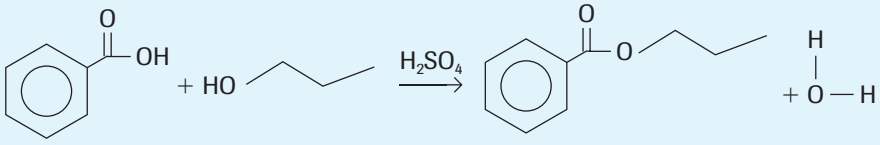
Draw a line structural formula equation and write the IUPAC name for the ester formed in the reaction between propan-1-ol and benzoic acid.

To name the ester:

- The first part of the name comes from the alcohol: propyl.
- The second part of the name comes from the acid: benzoate.
- The IUPAC name of the ester is propyl benzoate.

To draw the line structural formula:

- Draw structural formulas of the reactants and complete the condensation reaction.



benzoic acid propan-1-ol propyl benzoate water

SAMPLE problem 10.7

Write a condensed structural formula equation for the esterification reaction to produce the ester $CH_3CH_2CH_2COOCH_2CH_3$. Write IUPAC names for each reactant and product.

First, identify the acid (four carbons—butanoic acid) and the alcohol (two carbons—ethanol) that may be used in the synthesis of the ester. Then write condensed structural formulas and include the conditions in the chemical equation.

$$CH_3—CH_2—CH_2—COOH + HO—CH_2—CH_3 \xrightarrow{H_2SO_4}$$

butanoic acid ethanol

$$CH_3—CH_2—CH_2—COO—CH_2—CH_3 + H_2O$$

ethyl butanoate water

COMMUNICATION example 2

Name the ester CH_3COOCH_3 and the acid and alcohol from which it can be prepared.

What conditions are necessary?

Solution

The ester is methyl ethanoate, and it can be prepared from methanol and ethanoic acid.

A strong acid catalyst, such as $H_2SO_4(aq)$, is required, along with some heating.

Practice

3. Write a structural formula equation to illustrate the synthesis of each of the following esters from an alcohol and an acid. Refer to **Table 2** and identify the odour of each ester formed.
   (a) ethyl methanoate
   (b) ethyl benzoate
   (c) methyl butanoate
   (d) 3-methylbutyl ethanoate
4. Name each of the following esters, and the acids and alcohols from which they could be prepared:
   (a) $CH_3CH_2COOCH_2CH_3$
   (b) $CH_3CH_2CH_2COOCH_3$
   (c) $HCOOCH_2CH_2CH_2CH_3$
   (d) $CH_3COOCH_2CH_2CH_3$
5. Name the carboxylic acid and alcohol required to produce each of the following ester odours:
   (a) apricot
   (b) orange
6. The graph in **Figure 4** communicates evidence gathered for the boiling points of straight-chain carboxylic acids, methyl esters, and alkanes. (Methyl esters are prepared with methanol and their names begin with "methyl.") The boiling points are plotted against the molar masses of these organic compounds. The scientific purpose of this task is to test the explanatory power of the intermolecular force theories known to you.

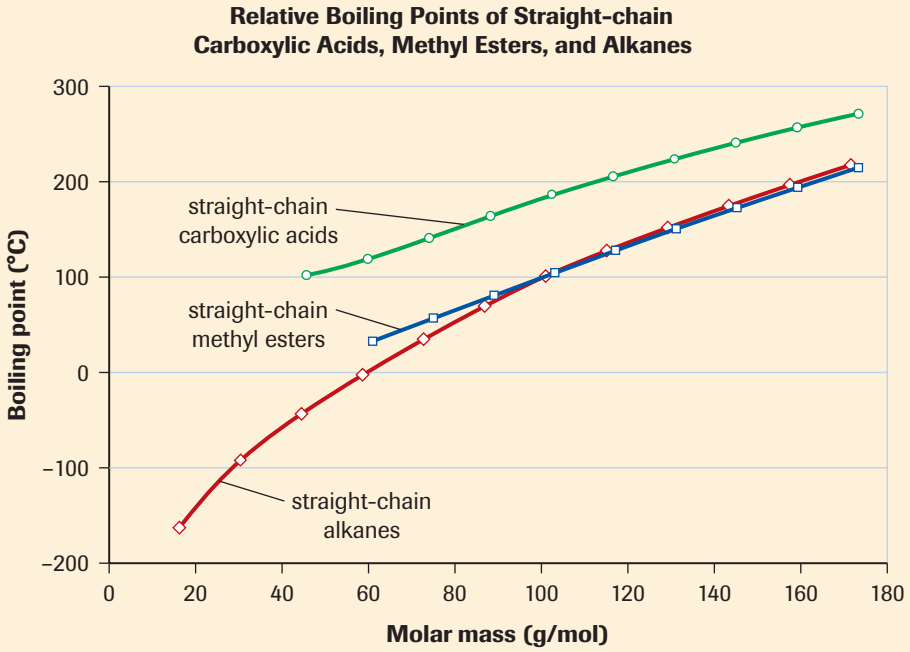


Figure 4
Boiling points of straight-chain carboxylic acids, methyl esters, and alkanes

(a) Explain the same upward trend in boiling points of the three classes of straight-chain organic compounds.
(b) Explain the relatively close boiling point values for the alkanes and the methyl esters.
(c) Explain the difference in boiling points for carboxylic acids versus alkanes and methyl esters with the same molar masses.

BIOLOGY CONNECTION

Natural Esters

Esters occur naturally. Beeswax, for example, is a natural ester containing chains 40–46 carbon atoms long. Plants' leaves are coated in waxy esters to minimize water loss; insects and animals may also have a surface coating (including skin) that includes esters. Chemical analysis of the coating on leaves shows that these natural esters (sometimes called wax esters) contain 34–62 carbon atoms. Of the natural waxes present on the surface of apples, for example, about 18% are esters.

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Learning Tip

You will find it helpful to memorize the functional groups for the classes of organic compounds that you have studied. A short summary (with the functional group in parentheses) is:

alkenes; e.g., $CH_2{=}CH_2$ (double bond)

alkynes; e.g., $CH{\equiv}CH$ (triple bond)

aromatics; e.g., $C_6H_5{-}CH_3$ (benzene ring(s))

organic halides; e.g., $CH_3{-}Cl$; R—X (X = F, Cl, Br and/or I)

alcohols; e.g., $CH_3{-}OH$; R—OH (hydroxyl group, —OH)

carboxylic acids; e.g., $CH_3{-}COOH$; R(H)—COOH (carboxyl group, —COOH)

esters; e.g., $CH_3{-}COO{-}C_2H_5$; R(H)COOR′ (ester group, —COO—)

R is a hydrocarbon chain/group. R(H) means that the R can be an H.

(d) Do your intermolecular force theories pass the test of being able to explain the relative boiling points of these straight-chain compounds? Give reasons for your answer.
(e) Why is the test restricted to comparing straight-chain compounds?
(f) Predict the position of the line representing the boiling point of alcohols, placed on this same set of axes.
(g) Referenced values of boiling points for some straight-chain alcohols include 64 °C for methanol, 97 °C for propan-1-ol, 138 °C for pentan-1-ol, and 176 °C for heptan-1-ol. Is your prediction in (f) verified or falsified? If falsified, critique your prediction and/or the hypothesis upon which you based your prediction.

7. What are some pros and cons, from at least two perspectives, for using artificial flavouring (manufactured esters) instead of natural flavours?

INVESTIGATION 10.3 *Introduction*

Synthesis of an Ester

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	○ Evaluation
○ Hypothesis	○ Procedure	
○ Prediction	● Evidence	

Purpose

The purpose of this investigation is to use the esterification generalization and diagnostic tests to synthesize and observe the properties of two esters.

Problem

What are some physical properties of ethyl ethanoate (ethyl acetate) and methyl salicylate?

Design

The esters are produced by the reaction of appropriate alcohols and acids, using sulfuric acid as a catalyst. The solubility and the odours of the esters are observed.

To perform this investigation, turn to page 463.

INVESTIGATION 10.4 *Introduction*

Testing with Models

Report Checklist

○ Purpose	○ Design	○ Analysis
○ Problem	● Materials	○ Evaluation
○ Hypothesis	○ Procedure	
○ Prediction	● Evidence	

Molecular models, either physical or electronic, are based on empirically known molecular structures. These models can then be considered as representing evidence collected in a variety of experiments. Recall stereochemical formulas from Chapter 3.

Purpose

The purpose of this investigation is to test stereochemical formula equations by using molecular models.

Problem

What are the stereochemical formula equations for the following reactions?
(a) methane undergoes complete combustion
(b) ethane is cracked into ethene
(c) propane reacts with chlorine
(d) but-2-ene reacts with water
(e) ethanol eliminates water to produce ethene
(f) 1-chloropropane undergoes an elimination reaction with hydroxide ions to produce propene, a chloride ion, and water
(g) ethanol reacts with methanoic acid

Design

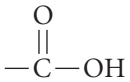
Physical or electronic models of the reactants and products for each reaction are constructed. The bonding and shapes of the molecules from the models are compared with the predictions.

To perform this investigation, turn to page 464.

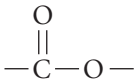
SUMMARY Carboxylic Acids, Esters, and Esterification

Functional groups

- carboxylic acid: –COOH carboxyl group

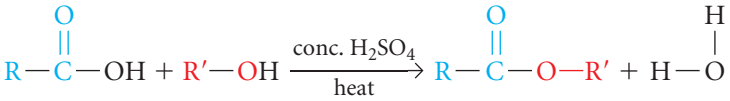


- ester: –COO– alkylated carboxyl group

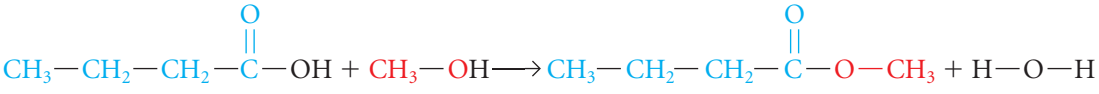


Esterification reaction

carboxylic acid + alcohol → ester + water



(For esterification, R can be replaced by an H, but R' cannot be replaced by an H.)

e.g., 

Learning Tip

Evidence of high boiling points and solubility indicates that, of the classes of organic compounds studied in this section, the following classes exhibit hydrogen bonding:

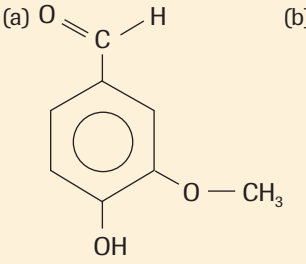
alcohols R — OH
carboxylic acids R or H — COOH

Esters, R^1COOR^2, do not exhibit hydrogen bonding.

Section 10.4 Questions

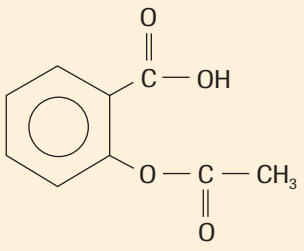
1. Prepare a table with the headings: Family, General Formula, and Naming System. Complete the table for the following organic families:
   (a) alcohols
   (b) carboxylic acids
   (c) esters
2. In what way is the functional group of an ester different from that of a carboxylic acid? How does this difference account for any differences in properties?
3. Design an experimental procedure for the synthesis of an ester, given ethanol and acetic acid. Describe the steps in the procedure, the safety equipment required, and the precautions needed in the handling and disposal of the materials.
4. Esters are often referred to as organic salts, and the esterification reaction is sometimes considered a neutralization reaction. An ester is similar, in some ways, to an ionic compound.
   (a) Use chemical formulas and equations to identify similarities and differences between esters and inorganic salts.
   (b) Design an investigation to determine which of two unlabelled pure samples provided to you is an ester and which is an ionic compound. List several diagnostic tests.
5. Many organic compounds have more than one functional group in a molecule. Copy the following structural formulas. Circle and label the functional groups for an alcohol, a carboxylic acid, and/or an ester. Suggest either a source or a use for each of these substances.

(a)



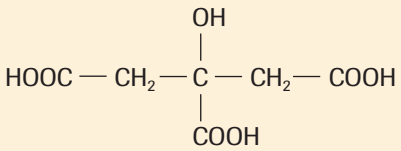
vanillin

(b)



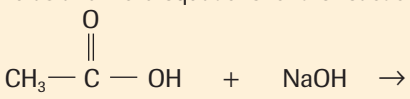
acetylsalicylic acid (ASA)

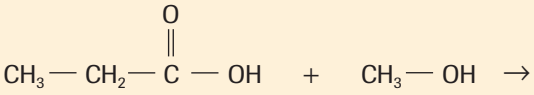
(c)



citric acid

6. Carboxylic acids, like inorganic acids, can be neutralized by bases. Carboxylic acids also undergo organic reactions. Classify the following reactions as neutralization or esterification. Write the complete condensed structural formulas and word equations for the reactions.

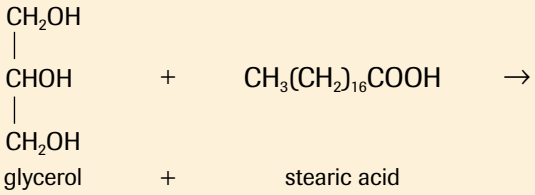
(a)


(b)


(c) benzoic acid + potassium hydroxide →

(d) ethanol + methanoic acid →

7. Fats and oils are naturally occurring esters that store chemical energy in plants and animals. Fatty acids, such as octadecanoic acid (also known as stearic acid), typically combine with propane-1,2,3-triol, known as glycerol, to form fat, a triester. Complete the following chemical equation by predicting the structural formula for the ester product.



glycerol + stearic acid

8. Classify the chemicals and write a complete balanced structural formula equation for each of the following predicted organic reactions. Where possible, classify the reactions and name the compounds as well. Assume that catalysts are used where required (for most of the reactions).

(a) $C_2H_6 + Br_2 \rightarrow C_2H_5Br + HBr$

(b) $C_3H_6 + Cl_2 \rightarrow C_3H_6Cl_2$

(c) $C_6H_6 + I_2 \rightarrow C_6H_5I + HI$

(d) $CH_3CH_2CH_2CH_2Cl + OH^- \rightarrow CH_3CH_2CHCH_2 + H_2O + Cl^-$

(e) $C_3H_7COOH + CH_3OH \rightarrow C_3H_7COOCH_3 + H_2O$

(f) $C_2H_5OH \rightarrow C_2H_4 + H_2O$

(g) $C_6H_5CH_3 + O_2 \rightarrow CO_2 + H_2O$

9. Complete the Prediction, Materials, Analysis, and Evaluation (2, 3) of the investigation report.

Purpose

The purpose of this investigation is to test the esterification reaction generalization.

Problem

What is the product of the reaction between benzoic acid and ethanol?

Design

Small quantities of benzoic acid and ethanol are mixed. A few drops of sulfuric acid catalyst are added. The mixture is heated and the product is tested for odour and solubility.

Evidence

The odour of cherries is observed.

The product has low solubility in water.

10. Bees build honeycomb cells from beeswax. Qualitative chemical analysis indicates that beeswax is an ester formed from mainly C_{26} and C_{28} straight-chain carboxylic acids and C_{30} and C_{32} straight-chain primary alcohols.

(a) Write a molecular formula equation for the formation of beeswax from the C_{26} carboxylic acid and the C_{32} alcohol.

(b) Use a molecular formula equation to represent the synthesis of beeswax from the C_{28} carboxylic acid and the C_{30} alcohol.

11. Use the information in this section and from your own research to continue gathering perspective statements concerning the statement that we should be saving more fossil fuels for petrochemical use in the future.

Extension

12. Tannic acid, originally obtained from the wood and bark of certain trees, has for centuries been used to "tan" leather.

(a) Give the structural formula for tannic acid.

(b) What effect does tannic acid have on animal hides? Explain your answer with reference to the chemical reactions that take place.

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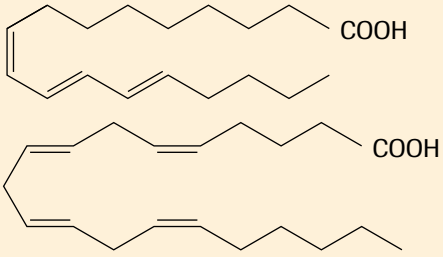
13. Transfats are formed when glycerol reacts with a carboxylic acid that has at least one double bond with a *trans* orientation. In a *trans* orientation, the hydrogen atoms are across the double bond from one another (compared to a *cis* orientation, where the hydrogens are on the same side of the double bond).

(a) Identify the number of *cis* and *trans* orientations found in the following two carboxylic acids. (See *cis* and *trans* isomers on page 423.)



(b) Transfats have been removed from most foods. What is the issue?

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Polymerization Reactions—Monomers and Polymers 10.5

If you take a look around you, you will likely find that you are surrounded by plastic products of many shapes and sizes. They may include pens, buttons, buckles, and parts of your shoes, chair, and lamp. There are plastic components in your calculator, telephone, computer, sporting equipment, and even the building in which you live. What are plastics and what makes them such desirable and versatile materials?

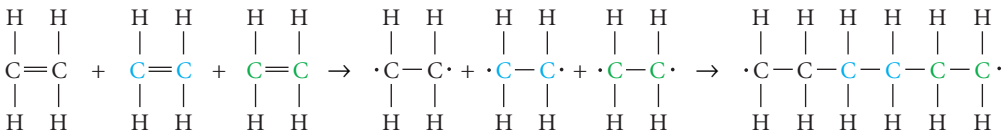
Plastics belong to a group of substances called **polymers**: large molecules made by linking together many smaller molecules, called **monomers**, much like paper clips in a long chain. Different types of small molecules form links in different ways, by either addition or condensation reactions. The types of small units and linkages can be manipulated to produce materials with desired properties such as strength, flexibility, high or low density, transparency, and chemical stability. As consumer needs change, new polymers are designed and manufactured.

Plastics are synthetic polymers, but many natural polymers have similar properties recognized since early times. Amber from tree sap, and tortoise shell, for example, can be processed and fashioned into jewellery or ornaments. Rubber and cotton are plant polymers, and wool and silk are animal polymers that have been shaped and spun into useful forms. In fact, our own cells manufacture several types of polymers—molecules so large and varied that they make us the unique individuals we are. Proteins and carbohydrates are all very different natural polymers.

Polymerization is the formation of polymers from the reaction of monomer subunits. These compounds have long existed in nature but were only synthesized by technological processes in the 20th century. They have molar masses up to millions of grams per mole.

Addition Polymers

Many plastics are produced by the polymerization of alkenes. For example, polyethene (polyethylene) is made by polymerizing ethene molecules in a reaction known as **addition polymerization**. Polyethylene is used to make plastic insulation for wires, and containers such as plastic milk bottles (**Figure 1**), refrigerator dishes, and laboratory wash bottles. Addition polymers are formed when monomer units join each other in a process that involves the rearranging of electrons in double or triple bonds in the monomer. The polymer is the only product formed.



ethene (ethylene)

part of polyethene (polyethylene)

The monomers form dimers (from two monomers) and trimers (from three monomers), and continue reacting to form polymers (from many monomers, dimers, and trimers).

Polypropylene, polyvinyl chloride (PVC), Plexiglas, polystyrene (Styrofoam®), and natural rubber are also addition polymers. The production process for polypropylene is illustrated in **Figure 2**.

EXTENSION

CBC radio ONE

QUIRKS & QUARKS

Plastics Under Pressure

Most plastics need to be heated and melted during recycling, but that same heat is damaging to the plastic, and degrades it into a less useful material. Researchers may have a solution to the problem: a new plastic that can be reformed under pressure instead of heat, and can be recycled many times. This technology could make recycling cheaper and much more environmentally friendly.

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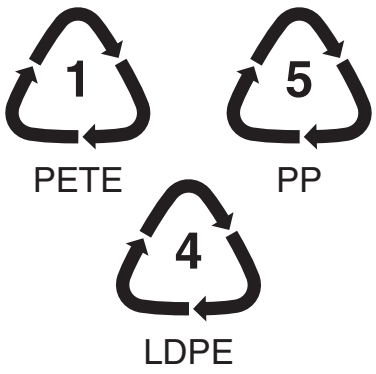


Figure 1

For recycling purposes, plastics (especially containers) are coded with a symbol for the type of plastic incorporated.

1. polyethylene terephthalate (PETE)
2. high-density polyethylene (HDPE)
3. polyvinyl chloride (PVC)
4. low-density polyethylene (LDPE)
5. polypropylene (PP)
6. polystyrene (PS)
7. other or mixtures

Look for these symbols on plastic products and, of course, recycle the product when you are finished with it.

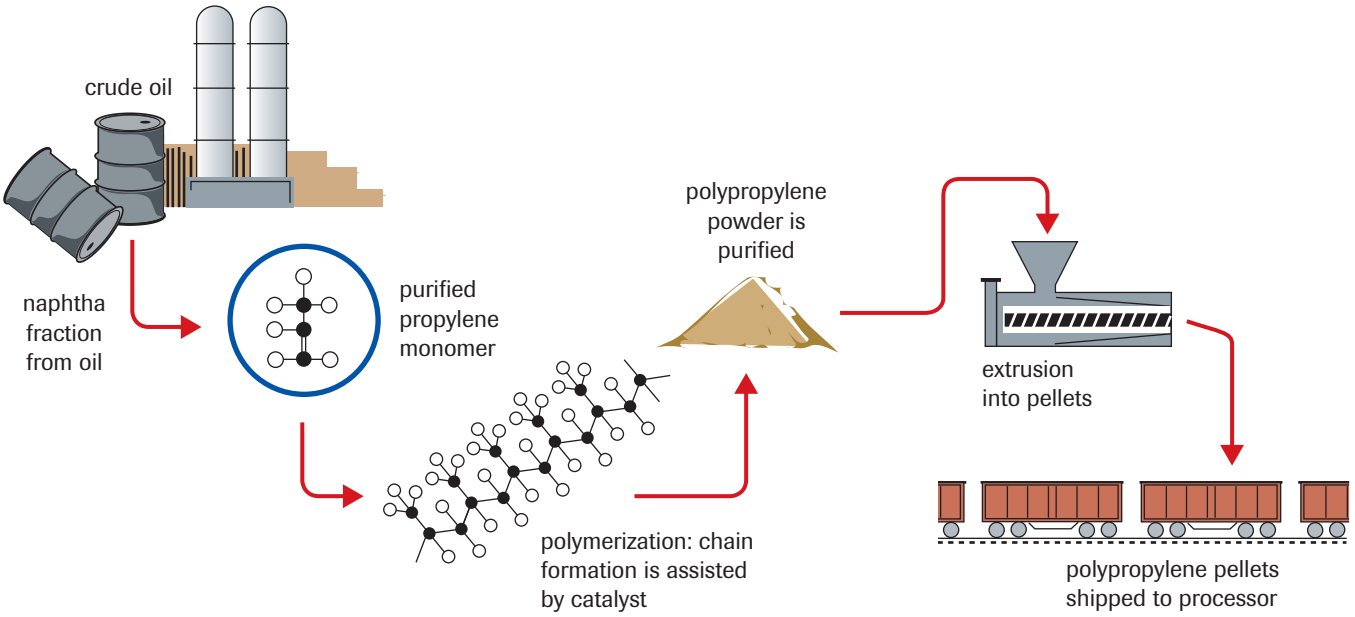

crude oil
naphtha fraction from oil
purified propylene monomer
polypropylene powder is purified
extrusion into pellets
polymerization: chain formation is assisted by catalyst
polypropylene pellets shipped to processor

Figure 2
The production of polypropylene from crude oil

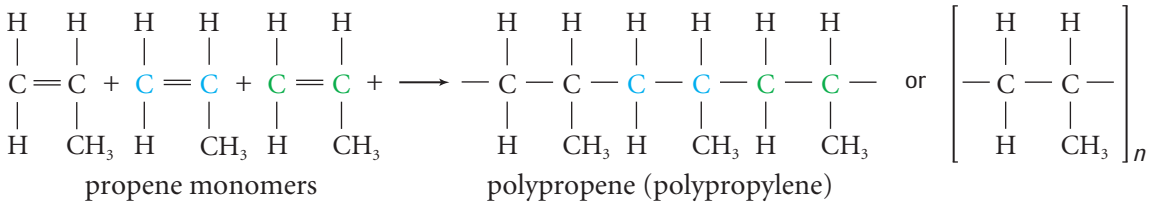
Figure 3
Polypropylene rope is one of many petrochemical products.

Other Addition Polymers: Carpets, Raincoats, and Insulated Cups

There are hundreds of different industrial polymers, all with different properties, and formed from different reactants.

Polypropene

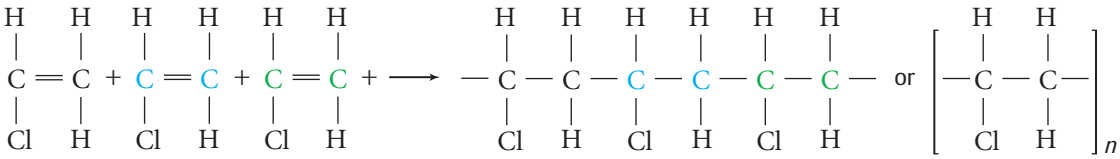
Propene also undergoes addition polymerization, producing polypropene, commonly called polypropylene. You may have used polypropylene rope (**Figure 3**), or walked on polypropylene carpet.



The polymerization reaction in the formation of polypropene is very similar to that of polyethene. The propene molecule can be considered as an ethene molecule with the substitution of a methyl group in place of a hydrogen atom. The polymer formed contains a long carbon chain, with methyl groups attached to every other carbon atom in the chain.

Polyvinyl Chloride

Ethene molecules with other substituted groups produce other polymers. For example, polyvinyl chloride, commonly known as PVC, is an addition polymer of chloroethene. A common name for chloroethene is vinyl chloride. PVC is used as insulation for electrical wires and as a coating on fabrics used for raincoats and upholstery materials (**Figure 4**).



vinyl chloride monomers — polyvinyl chloride (PVC)

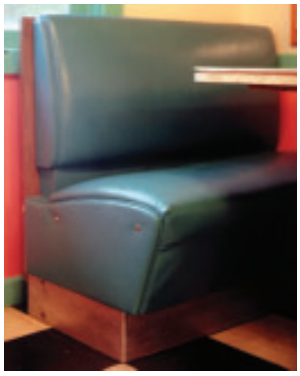
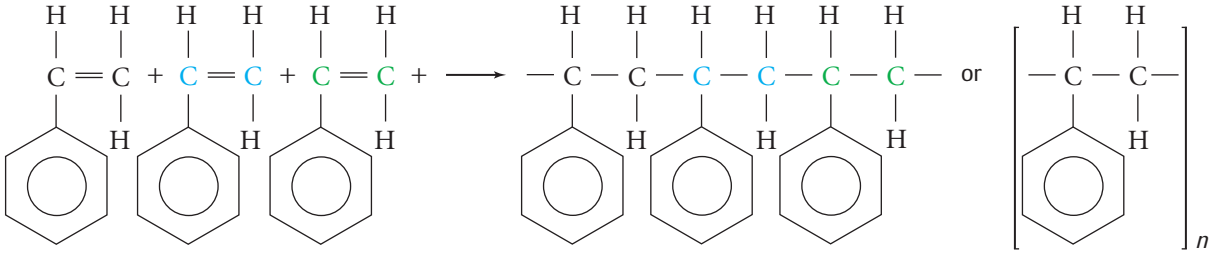


Figure 4
Polychloroethene or polyvinyl chloride is used for upholstery.

Polystyrene

When a benzene ring is attached to an ethene molecule, the molecule is vinyl benzene, commonly called styrene. An addition polymer of styrene is polystyrene, often used to make cups and containers. Look for the recycle symbol with a 6 and PS.



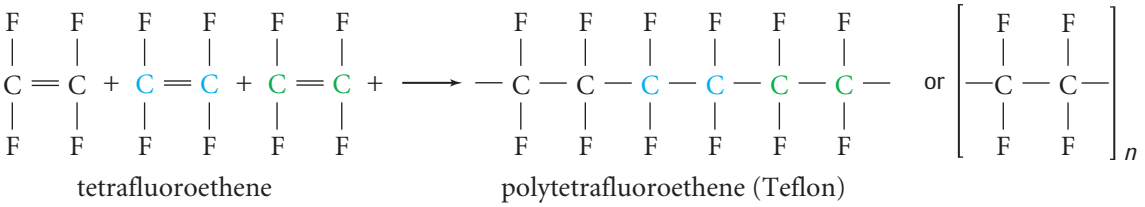
styrene monomers — polystyrene

Teflon

Teflon® is the common name for an addition polymer with nonstick properties that are much desired in cookware (**Figure 5**).

The monomer used to synthesize Teflon is the simple molecule tetrafluoroethene, $CF_2{=}CF_2$, an ethene molecule in which all hydrogen atoms are replaced with fluorine atoms. The absence of carbon–hydrogen bonds and the presence of the very strong carbon–fluorine bonds make Teflon highly unreactive with almost all reagents. It is this unreactivity that allows it to be in contact with foods at relatively high temperatures without "sticking." The inert (unreactive) nature of Teflon makes it a very useful polymer in a wide variety of applications. There is, however, some controversy about its safety, as you will discover in the following Web Activity.

Figure 5
The invention of Teflon has made life easier in many ways.

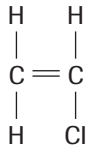


tetrafluoroethene — polytetrafluoroethene (Teflon)

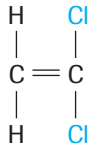
DID YOU KNOW ?

Addition Monomers

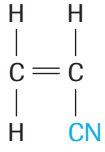
Ethene and its double-bonded derivatives are monomers for polymers with a wide variety of properties. Some of these monomers include:



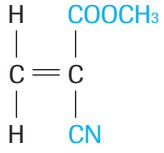
monomer of PVC



monomer of Saran™ wrap



monomer of acrylic



monomer of instant glue

WWW WEB Activity

Web Quest—Teflon: Healthy or Hazardous?

Cooks used to coat pots and pans with butter or oil to keep food from sticking, but the result was greasy high-fat food. The invention of Teflon®, a non-stick cooking surface, changed all this. Recently, concern has been growing regarding the possibility that Teflon® releases toxic chemicals if it gets too hot. Research the pros and cons of Teflon®, and decide for yourself if the risks are worth the benefits.

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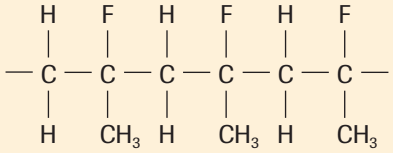
Practice

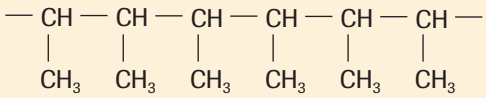
1. Draw a structural formula of three repeating units of
(a) a polymer of but-1-ene
(b) a polymer of vinyl fluoride
(c) a polymer of 1-chloro-1,2,2-trifluoroethene
(d) Predict the properties of the polymer in (c) in terms of solubility in organic solvents, rigidity, and resistance to heating.

2. Draw a structural formula of the monomer of the following polymer:

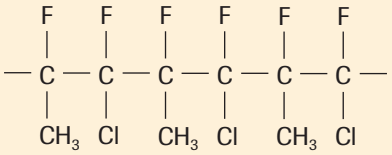


3. What monomer could be used to produce each of these polymers?

(a)



(b)



4. What functional group(s), if any, must be present in a monomer that undergoes an addition polymerization reaction?

5. Addition polymers may be produced from two different monomers, called co-monomers. Saran™, the polymer used in a brand of food wrap, is made from the monomers vinyl chloride and 1,1-dichloroethene. Draw structural formulas for each monomer, and for three repeating units of the polymer, with alternating co-monomers.

6. (a) What are the typical properties of a plastic?
(b) What types of bonding would you expect to find within and between the long polymer molecules?
(c) Explain the properties of plastics by referring to their bonding.

7. Polymerization is a term used for a crude-oil refining process that converts small alkenes into gasoline-sized molecules. The polymerization process is controlled to produce dimers and trimers only (not large polymers), using phosphoric acid as a catalyst. Provide a structural formula equation for the reaction of
(a) three molecules of ethene
(b) propene and but-1-ene
(c) but-1-ene and but-2-ene

8. Find out from your community recycling facility what types of plastic products are accepted for recycling in your area. If there are some plastics that are not accepted, find out the reason. Summarize your findings in a well-organized table.

WEB Activity

Case Study—Recycling Plastics

Much of the plastic we use today is collected. We sometimes think of collecting as "recycling," but true recycling only happens if the plastic is used to make a product similar to the original one. How is recycling done? Investigate several Web sites and gather information to write a procedure for processing recycled plastic. Also, collect some pros and cons from multiple perspectives concerning the use of plastics.

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Condensation Polymers

Some polymers, including the synthetic fibres nylon and polyester, and natural polymers like proteins and DNA, are produced by **condensation polymerization** reactions. These reactions involve the formation of a small molecule (such as H_2O, NH_3, or HCl) from the functional groups of two different monomer molecules. The small molecule is said to be "condensed out" of the reaction. The monomer molecules bond at the site where atoms are removed from their functional groups. To form a condensation polymer, the monomer molecules must each have at least two functional groups, one on each end.

Comparing Natural with Synthetic Polymers

Research chemists have found that Nature has many well-designed molecular structures that are polymers. Many synthetic condensation polymers are structural analogs of the nutrient molecules found in foods: they have structures similar to those of lipids (fats and oils), proteins, and carbohydrates. Over the next few pages, there is a classification and description of some of these natural polymers: proteins and carbohydrate polymers. Most of us recognize these classes of compounds as categories of foodstuffs. Food labels usually list the mass of fat, protein, and carbohydrate per serving.

A synthetic compound that has a similar chemical structure to a naturally occurring substance is called a structural analog. For example, nylon is a structural analog of protein, but not a functional analog (**Figure 6**). Functional analogs are synthetic compounds that perform the same function as a naturally occurring substance but do not necessarily have similarities in chemical structure. For example, synthetic sweeteners are functional analogs of sweet carbohydrates: sugars. Chemists who study natural chemicals in order to prepare synthetic copies are called natural-product chemists.

Natural Product (food nutrient molecules)	Lipids	Proteins	Carbohydrates
	↓	↓	↓
Structural Analog (synthetic polymers)	Polyesters	Nylon	Cellulose Polymers

Figure 6
Food nutrients and their synthetic structural analogs are an example of natural product chemistry, where chemists copy and modify the structure of chemicals found in nature.

Lipids and Polyesters

Lipids (fats and oils) are formed by esterification reactions between glycerol (propane-1,2,3-triol) and fatty acids (long-chain carboxylic acids). Since glycerol has three hydroxyl (–OH) groups, three molecules of fatty acid can react with each glycerol molecule to form a tri-ester. This reaction is a condensation reaction that is not, strictly speaking, a polymerization reaction: The largest molecule formed is a tri-ester.

DID YOU KNOW?

Photodegradable Polymers

James Guillet (1927–2005), a Canadian green-chemist, used his fascination with photosynthesis to inspire his study of the photochemistry of synthetic systems. While on holidays in the Bahamas, he was disturbed by the quantity of plastic litter and realized that, with his knowledge, he could "make it disappear." Guillet registered three patents for photodegradable polymers in 1970. Unfortunately, his invention was not widely embraced. Self-interests lobbied against his "human-made plastics."

DID YOU KNOW?

Aboriginal Technologies

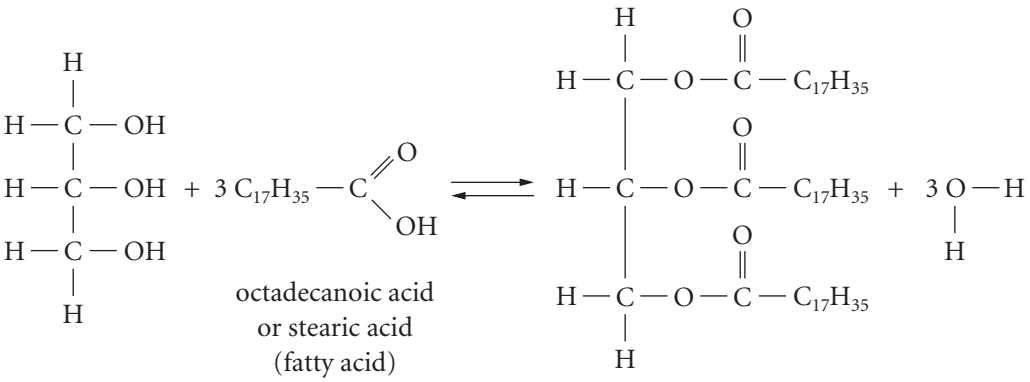
Aboriginal peoples used many natural materials to create useful technologies. For example, Aboriginal peoples invented the birch-bark canoe, seal-skin kayak, rawhide and willow snowshoes, and animal skin tipis. The natural polymers, such as cellulose and protein, in these Aboriginal technologies have, in some cases, been replaced by synthetic polymers.

Learning Tip

You are not required to learn the names of carboxylic acids beyond ten carbons. You also do not have to name the triesters representing fats and oils. You should, however, learn the general structures of

- polyalcohols (especially propane-1,2,3-triol),
- saturated and unsaturated fatty acids, and
- triester fats and oils.

glycerol + saturated fatty acid ⇄ saturated fat + water



propane-1,2,3-triol (glycerol)

octadecanoic acid or stearic acid (fatty acid)

glyceryltrioctadecanoate or tristearin or glyceryltristearate (saturated fat present in butter and lard)

BIOLOGY CONNECTION

Correlation versus Cause and Effect

Many biochemistry studies related to food are correlational studies. These studies look for a correlation (relationship) between two variables (without being able to control all other variables—as a cause–effect study would). For example, scientists found a strong correlation between saturated fats (and transfats), and artery and heart diseases. Chemists responded with creative solutions (**Figure 7**).

Figure 7
Butter and margarine are examples of saturated and unsaturated fats (lipids). There are many criteria that can be used to evaluate which is the best product.

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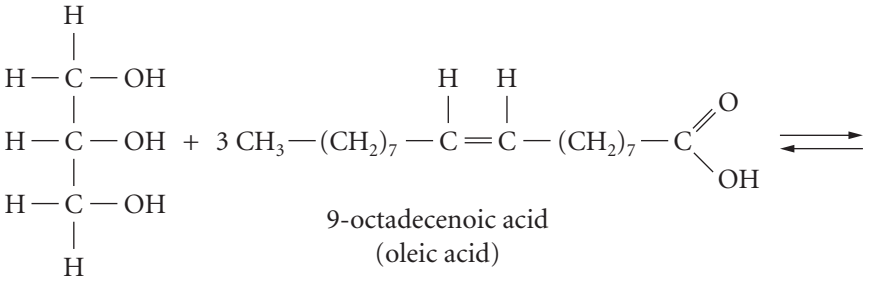
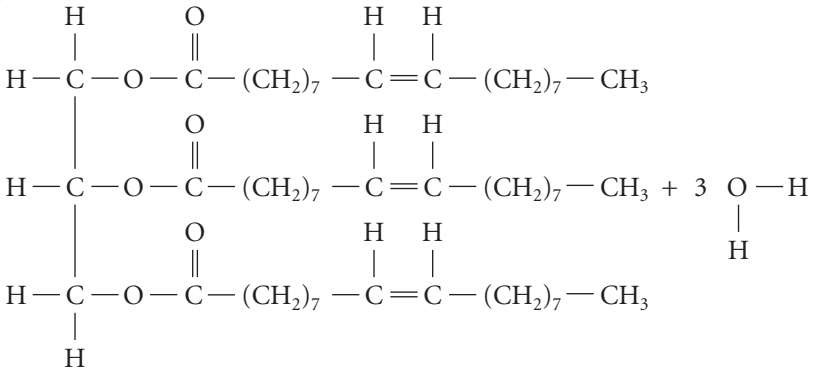
glycerol + unsaturated fatty acid ⇄ unsaturated oil + water



propane-1,2,3-triol (glycerol)

9-octadecenoic acid (oleic acid)



glyceryltri (9-octadecenoate) (triolein, an unsaturated *cis* fat present in olive oil)

At one time, unsaturated fats were considered to be healthier in the diet than saturated fats and oils. Unsaturated oils are generally liquids at room temperature. To change the oil into a solid (such as margarine), the unsaturated fat is partially hydrogenated to remove some of the double bonds and increase the melting point. Subsequent research showed that, although unsaturated fats were healthier, the hydrogenation process created unhealthy transformed fats.

Practice

9. Unsaturated lipids are generally more liquid (i.e., oils), and saturated lipids are generally more solid (i.e., fats). Create a hypothesis to explain the difference between the melting points of unsaturated versus saturated lipids.

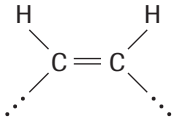
10. The fatty acid $C_{19}H_{39}COOH$ reacts with glycerol, $C_3H_5(OH)_3$, to produce peanut oil. Write a structural formula equation to communicate this reaction.

11. The fatty acid $CH_3—(CH_2)_7—CH{=}CH—(CH_2)_7—COOH$ is hydrogenated. Write a structural formula equation for this chemical reaction.

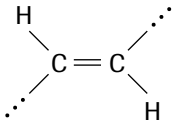
DID YOU KNOW ?

Transfat

A transfat has a double bond where the hydrogen atoms are on the opposite side of the double bond. *Trans* means across, so the hydrogen atoms are across the double bond from one another.



cis orientation



trans orientation

Polyesters

When a carboxylic acid reacts with an alcohol in an esterification reaction, a water molecule is eliminated and a single ester molecule is formed. The two reactant molecules are linked together into a single ester molecule. This esterification reaction can be repeated to form not just one ester molecule, but many esters joined in a long chain, a **polyester**. This is accomplished using a dicarboxylic acid (an acid with a carboxyl group at each end of the molecule), and a diol (an alcohol with a hydroxyl group at each end of the molecule). Ester linkages can then be formed end to end between alternating acid molecules and alcohol molecules.

$$\overline{HO}\,OC—CH_2—CH_2—CO\,\boxed{OH + H}\,O—CH_2—CH_2—O\,\boxed{H + HO}\,OC—CH_2—CH_2—CO\,\boxed{OH} + \rightarrow$$

ethane-1,2-dicarboxylic acid — ethane-1,2-diol

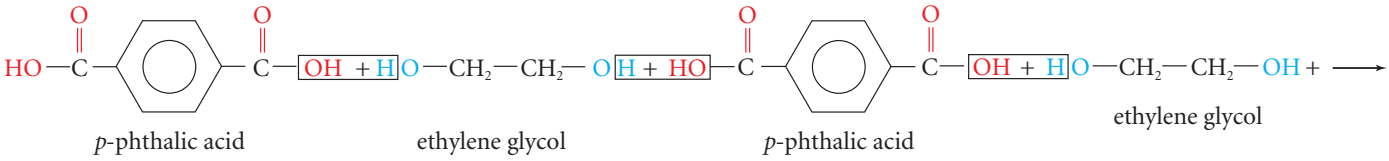
$$—OC—CH_2—CH_2—CO—OCH_2—CH_2O—OC—CH_2—CH_2—CO— + H_2O(l)$$

If we were to depict the acid with the symbol $\Delta — \Delta$, the alcohol with $o — o$, and the ester linkage with $\boxed{o\Delta}$, we could represent the polymerization reaction like this:

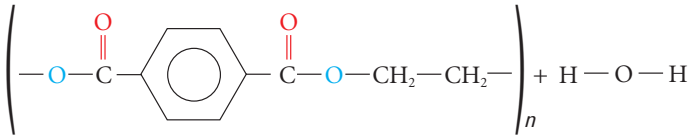
$$\Delta—\Delta + o—o + \Delta—\Delta + o—o \rightarrow —\Delta— \boxed{\Delta o}—\boxed{o\Delta}—\boxed{\Delta o}—o— + \text{water}$$

polyester

Dacron®, another polyester, is made from *p*-phthalic acid (p-dibenzoic acid) and ethane-1,2-diol (ethylene glycol). Note the two carboxyl groups in the dicarboxylic acid and the two hydroxyl groups in the polyalcohol that start the chain reaction.



p-phthalic acid — ethylene glycol — *p*-phthalic acid — ethylene glycol



a polyester (Dacron®)

DID YOU KNOW ?

Amines and Amides

Two classes of organic compounds that are not studied in detail in this textbook are amines and amides. The simplest amines have the $-NH_2$ (amino) functional group, as in $R-NH_2$. The simplest amides have the $-CONH_2$ functional group in a molecule of $R-CONH_2$. A polyamide may be formed naturally or technologically by repeatedly reacting a carboxyl group with an amino group. The –CONH– group is called an amide (or peptide) linkage. Proteins and nylon are polymers that are called polyamides. Protein polymers are specifically called polypeptides.

Practice

12. Draw a structural formula equation to show a repeating unit of a condensation polymer formed from the following compounds:

$HOOC-CH_2-CH_2-COOH$ and $HO-CH_2-CH_2-CH_2-CH_2-OH$

13. What functional groups must be present to form a polyester?

14. How are the reactions to form fats and to form polyesters similar and different?

WEB Activity

Simulation—Molecular Modelling

Molecular modelling has become more of a computer activity than a physical activity. Chemists routinely use interactive models to better understand how the shapes of compounds affect their properties. Check out some of the molecular modelling Web sites.

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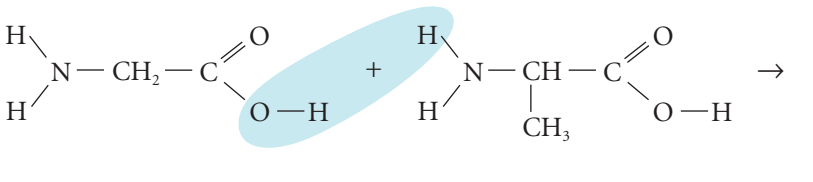
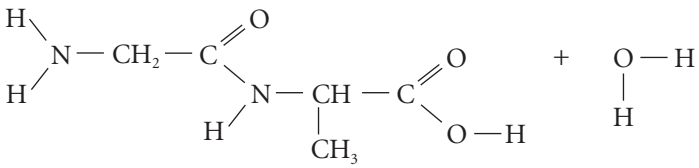
Proteins and Nylon

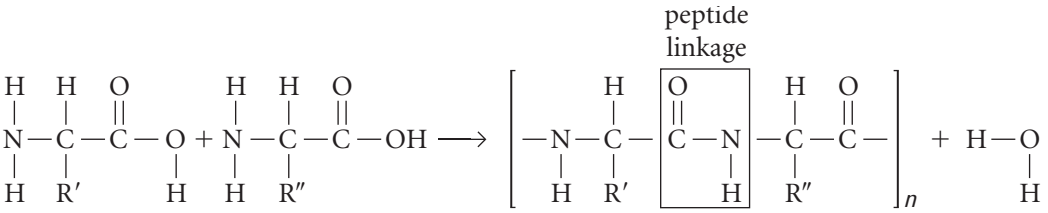
Proteins are a fundamental structural material in plants and animals. Scientists estimate that there are more than ten billion different proteins in living organisms on Earth. Remarkably, all of these proteins are constructed from only about 20 amino acids. Through a reaction that involves the carboxyl group and the amine ($-NH_2$) group, amino acids polymerize into peptides (short chains of amino acids) or proteins (long chains of amino acids). The condensation reaction of the amino acids glycine and alanine illustrates the formation of a dipeptide. Condensation polymerization produces a protein, with a molar mass tens of thousands to millions of grams per mole—thousands of monomers long.





glycine + alanine → a dipeptide + water

The dipeptide reacts with itself or with more glycine and/or alanine. Of course, other amino acids may be present to produce an even more complex peptide. The polypeptide produced by polymerization is a protein with peptide (–CONH–) linkages. The following general equation illustrates the formation of a protein from amino acids.



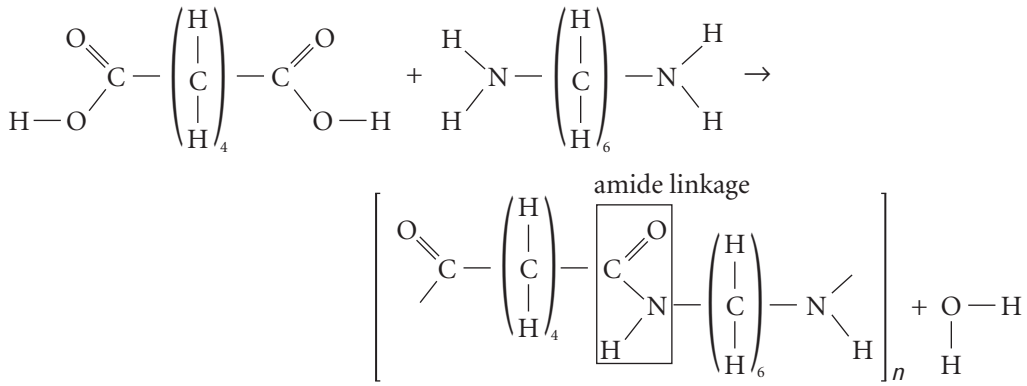
amino acid 1 amino acid 2 polypeptide segment

DID YOU KNOW ?

Nylon

Nylon was designed in 1935 by Wallace Carothers, a chemist who worked for DuPont; the name *nylon* is a contraction of New York and London.

Many synthetic polymers, such as nylon, form in similar ways to proteins. Nylon is a synthetic condensation polymer. For both the natural polymer (protein) and the synthetic polymer (nylon), the polymer forms by the reaction of a carboxyl group (–COOH) with a $–NH_2$ group with amide linkages (–CONH–). Polymers with amide linkages are called **polyamides**. Amide linkages in proteins are called peptide linkages and the polymers are called **polypeptides**.



hexane-1,6-dioic acid + 1,6-diaminohexane → part of the nylon 6,6 polymer chain + water

INVESTIGATION 10.5 *Introduction*

Preparing Nylon 6,10 (Demonstration)

Nylon was considered the "miracle" fibre when it was discovered in 1935. At the time, nylon was unique because it was the first synthetic fibre produced from petrochemicals. It initiated an entire new world of manufactured fibres. In this demonstration, sebacoyl chloride, $COCl(CH_2)_8COCl(l)$, reacts with 1,6-diaminohexane to produce one type of nylon. For the prediction, write a condensed or line structural formula equation showing the formation of the polymer.

Purpose

The purpose of this demonstration is to use your knowledge of condensation polymerization to explain the formation of a nylon polymer.

Report Checklist

○ Purpose	○ Design	○ Analysis
○ Problem	○ Materials	○ Evaluation
○ Hypothesis	○ Procedure	
● Prediction	● Evidence	

Problem

How does the combination of sebacoyl chloride and 1,6-diaminohexane form the polymer known as nylon 6,10?

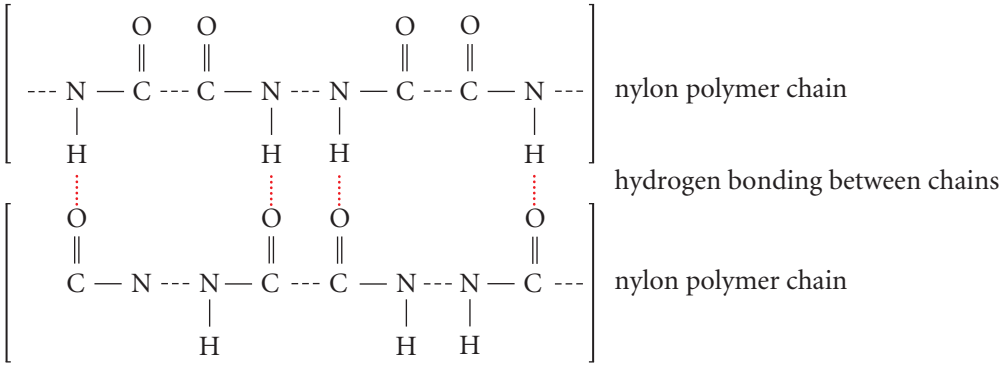
Design

A solution of 1,6-diaminohexane is carefully poured on top of an aqueous solution of sebacoyl chloride. The nylon that forms at the interface of the two layers is slowly pulled out of the mixture using forceps.

To perform this investigation, turn to page 464.

Nylon was synthesized as a substitute for silk, a natural polyamide whose structure nylon mimics. The onset of the Second World War speeded up nylon production to make parachutes, ropes, cords for aircraft tires, and even shoelaces for army boots. It is the –CONH groups that make nylon such a strong fibre. When spun, the long polymer

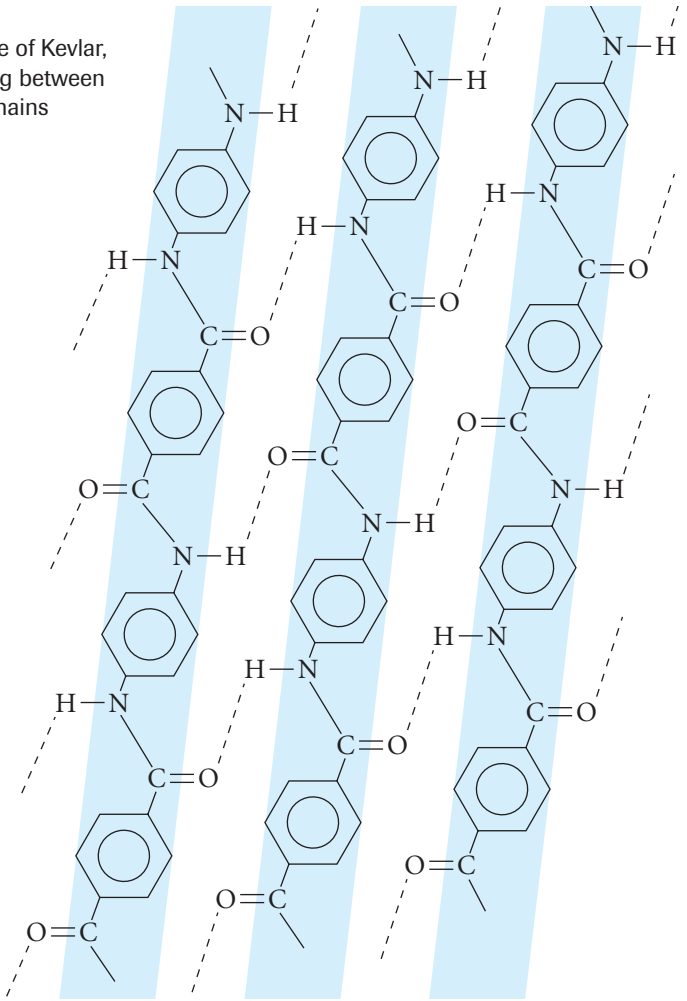
chains line up parallel to each other, and the –CONH groups form hydrogen bonds with –CONH groups on adjacent chains.



Kevlar

To illustrate the effect of hydrogen bonding in polyamides, consider a polymer with very special properties. It is stronger than steel and heat resistant, yet is lightweight enough to wear. This material is called Kevlar® (**Figure 9**) and is used to make products such as aircraft, sports equipment, protective clothing for firefighters, and bulletproof vests for police officers. What gives Kevlar these special properties? The polymer chains form a strong network of hydrogen bonds holding adjacent chains together in a sheet-like structure. The sheets are in turn stacked together to form extraordinarily strong fibres. When woven together, these fibres are resistant to damage, even that caused by a speeding bullet.

Figure 9
The chemical structure of Kevlar, with hydrogen bonding between the shaded polymer chains



DID YOU KNOW ?

Pulling Fibres

When a polymer is to be made into a fibre, the polymer is first heated and melted. The molten polymer is then placed in a pressurized container and forced through a small hole, producing a long strand, which is then stretched (**Figure 8**). The process, called extrusion, causes the polymer chains to orient themselves lengthwise along the direction of the stretch. Covalent or hydrogen bonds form between the chains, giving the fibres added strength.

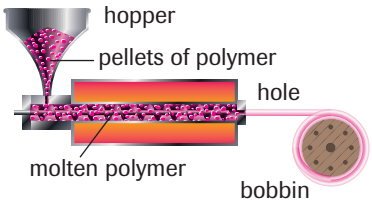


Figure 8
Making a polymer

DID YOU KNOW ?

Paintball: A Canadian Invention

The sport of paintball was invented in Windsor, Ontario. Paintballs were first used to mark cattle for slaughter and trees for harvesting, using oil-based paints in a gelatin shell. When recreational paintball use demanded a water-based paint, the water-soluble gelatin shell was modified by adjusting the ratio of the synthetic and natural polymers used.

Practice

15. What kind of polymerization does the formation of a polyamide (natural or synthetic) involve?

16. Provide one example each of a natural and of a similar synthetic condensation polymer.

17. Draw a structural formula representation of the nylon 6,8 repeating unit, formed by reacting $H_2N(CH_2)_6NH_2$ and $HOOC(CH_2)_6COOH$.

EXPLORE an issue

Issue Checklist

○ Issue	○ Design	● Analysis
○ Resolution	● Evidence	● Evaluation

Natural or Artificial Polymers?

From the time your grandparents were babies to the time you were born, diapers have been made entirely of polymers. Cotton cloth diapers were, and still are, made of cellulose, a natural polymer. Nowadays, disposable diapers, made mainly of synthetic polymers, are a popular choice. Which is better for the baby? How do they affect our environment? The typical disposable diaper has many components, mostly synthetic plastics, that are designed with properties particularly desirable for its function.

- *Polyethylene film*: The outer surface is impermeable to liquids, to prevent leakage. It is treated with heat and pressure to appear cloth-like for consumer appeal.
- *Hot melts*: Different types of glue are used to hold components together. Some glues are designed to bond elastic materials.
- *Polypropylene sheet*: The inner surface at the leg cuffs is designed to be impermeable to liquids and soft to the touch. The main inner surface is designed to be porous, to allow liquids to flow through and be absorbed by the bulk of the diaper.
- *Polyurethane, rubber, and Lycra*: Any or all of these stretchy substances may be used in the leg cuffs and the waist-band.
- *Cellulose*: Basically processed wood pulp, this natural polymer is obtained from pine trees. It forms the fluffy filling of a diaper, absorbing liquids into the capillaries between the fibres.
- *Polymethylacrylate*: This crystalline polymer of sodium methylacrylate absorbs water through osmosis and hydrogen bonding. The presence of sodium ions in the polymer chains draws water that is held between the chains. The presence of water results in attractions between the chains and causes the formation of a gel (**Figure 10**).

Manufacturers claim that grains of sodium polymethylacrylate can absorb up to 400 times their own mass in water. If sodium ions are present in the liquid, they act as contaminants, reducing absorbency because the attraction of water to the polymer chains is diminished. Urine always contains sodium ions, so the absorbency of diapers for urine is actually less than the advertised maximum.

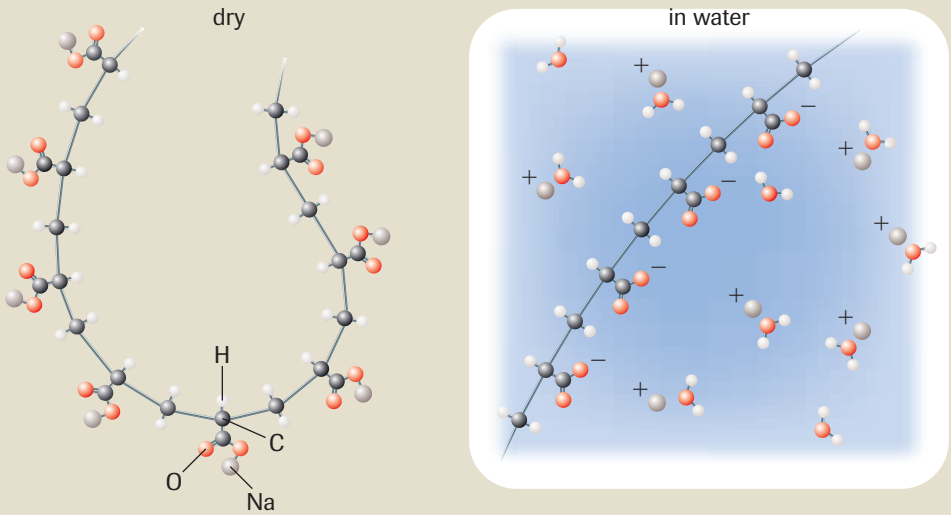


Figure 10
Polymethylacrylate

Proponents of natural products argue that disposable diapers pose a long-term threat to our environment, filling waste disposal sites with non-biodegradable plastics for future centuries. The industry has developed some new "biodegradable" materials—a combination of cellulose and synthetic polymers, for example. Some of these materials have proven too unstable to be practical, while others appear to biodegrade in several years, which gives the diapers a reasonable shelf life. The energy and raw materials needed to manufacture the huge quantity of disposable diapers used is also of concern. Diaper manufacturers and their supporters argue, however, that using the natural alternative—cloth diapers—consumes comparable amounts of energy in the laundry. In addition, the detergents used in the cleaning process are themselves non-biodegradable synthetic compounds made from petroleum products.

Issue
Do cloth diapers pose less of a threat to the environment than disposable diapers?

Resolution
Consumers should return to using cloth diapers in order to protect the environment.

Design
Within small groups, research the pros and cons of using cloth diapers. Gather information from a wide variety of perspectives.

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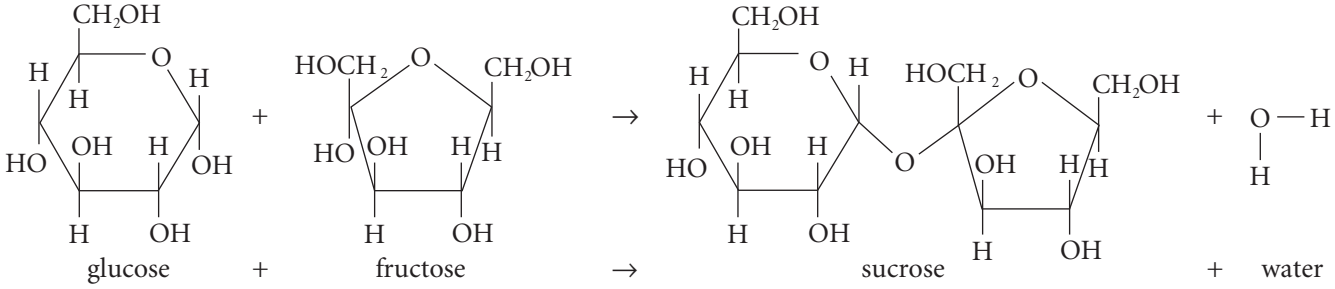
Carbohydrates and Cellulose Acetate

The monomers of carbohydrates—compounds with the general formula $C_x(H_2O)_y$—are simple sugar molecules. The sugar monomers undergo a condensation polymerization reaction in which a water molecule is formed, and the monomers join together to form a larger molecule. For example, the sugar monomers glucose and fructose can form sucrose (table sugar) and water. Both starch and cellulose consist of long chains of glucose molecules. Simple sugar monomers are sometimes called monosaccharides; dimers are called disaccharides; and polymers are called polysaccharides.



Starch for Energy; Cellulose for Support

Starchy foods such as rice, wheat, corn, and potatoes provide us with readily available energy. They are also the main method of energy storage for the plants that produce them, as seeds or tubers. Starches are polymers of glucose, in either branched or unbranched chains; they are, thus, polysaccharides.

We have, in our digestive tracts, very specific enzymes. One breaks down starch. However, the human digestive system does not have an enzyme to break down the other polymer of glucose: cellulose. Cellulose is a straight-chain, rigid polysaccharide with glucose–glucose linkages different from those in starch or glycogen. It provides structure and support for plants, some of which tower tens of metres in height. Wood is mainly cellulose; cotton fibres and hemp fibres are also cellulose. Indeed, it is because cellulose is indigestible that whole grains, fruits, and vegetables are good sources of dietary fibre.

It is the different glucose–glucose linkages that make cellulose different from starch. When glucose forms a ring structure, the functional groups attached to the ring are fixed in a certain orientation above or below the ring. Our enzymes are specific to the

DID YOU KNOW?

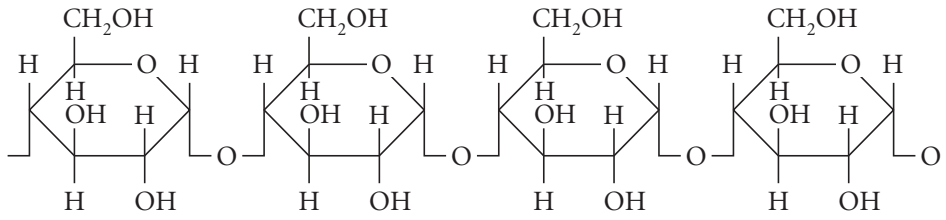
Maple Sugar and Corn

Canadian Aboriginal peoples introduced Europeans to maple sugar. Sugar (a disaccharide) can be obtained from sugar cane (from South America) and sugar beets (from southern Alberta). The greatest contribution of Aboriginal agriculture is corn—one of the most prolific and widespread crops in human history—from which we obtain corn syrup.

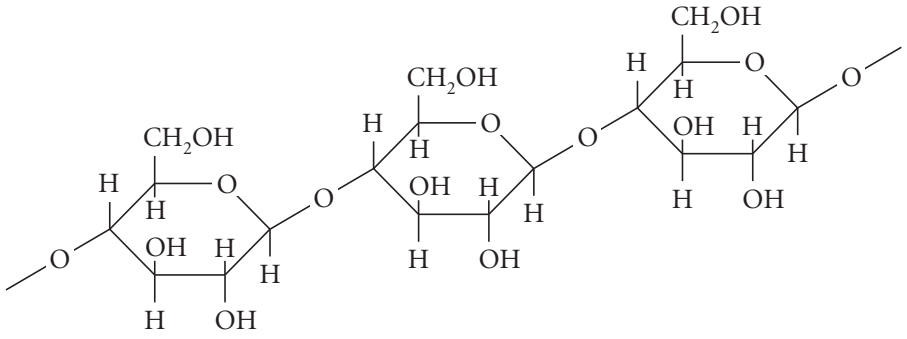
orientation of the functional groups, and cannot break the glucose–glucose linkages found in cellulose. Herbivores such as cattle, rabbits, termites, and giraffes rely on some friendly help to do their digesting: They have specially developed stomachs and intestines that house enzyme-producing bacteria or protozoa to aid in the breakdown of cellulose.

In starch, glucose monomers are added at angles that lead to a helical structure, which is maintained by hydrogen bonds between –OH groups on the same polymer chain (**Figure 11(a)**). The single chains are sufficiently small to be soluble in water. Thus, starch molecules are both mobile and soluble—important properties in their role as readily available energy storage for the organism.

In cellulose, glucose monomers are added to produce linear polymer chains that can align side by side, favouring interchain hydrogen bonding (**Figure 11(b)**). These interchain links produce a rigid structure of layered sheets of cellulose. This bulky and inflexible structure not only imparts exceptional strength to cellulose; it also renders it insoluble in water. It is, of course, essential for plants that their main building material does not readily dissolve in water.



(a) starch



(b) cellulose

Figure 11

The difference in linkages between glucose monomers gives very different three-dimensional structures.

(a) In starch, the polymer takes on a tightly coiled helical structure.

(b) In cellulose, the linked monomers can rotate, allowing formation of straight fibres.

BIOLOGY CONNECTION

Glycogen

Animals also produce a starch-like substance, called glycogen, that performs an energy storage function. Glycogen is stored in the muscles as a ready source of energy, and also in the liver, where it helps to regulate blood glucose levels.

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DID YOU KNOW

Cotton—A Natural Polymer

North American Aboriginal peoples made extensive use of cotton for clothing. This technology was exported to Europe, where it contributed to starting the industrial revolution in Britain. Cotton is a natural carbohydrate (cellulose) polymer. There are now regenerated (manufactured) fibres from cellulose, such as cellulose acetate and cellulose nitrate. In 1850, long-fibre cotton comprised over 50% of Britain's exports. The mechanization and infrastructure developed for processing cotton, and the resulting capital gained, helped to fuel and shape the Industrial Revolution.

mini Investigation — Starch and Cellulose

Use a molecular model kit and/or a computer program to construct and/or investigate molecular models of glucose, sucrose, starch, and cellulose.

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DID YOU KNOW ?

The Centre of the Chocolate

Sucrose, a disaccharide, is slightly sweeter than glucose but only half as sweet as fructose. The enzyme sucrase, also called invertase, can break sucrose down into glucose and fructose—a mixture that is sweeter and more soluble than the original sucrose. The centres of some chocolates are made by shaping a solid centre of sucrose and invertase, and coating it with chocolate (**Figure 12**). Before long, the enzyme transforms the sucrose centre into the sweet syrupy mixture of glucose and fructose.

Figure 12
Invertase breaks sucrose down to glucose and fructose in some chocolates.

Practice

18. Identify the functional groups present in a molecule of glucose and in a molecule of fructose.

19. Describe several functions of polysaccharides and how their molecular structures serve these functions in plants.

20. Compare the following pairs of compounds, referring to their structure and properties:
(a) sugars and starch
(b) starch and cellulose

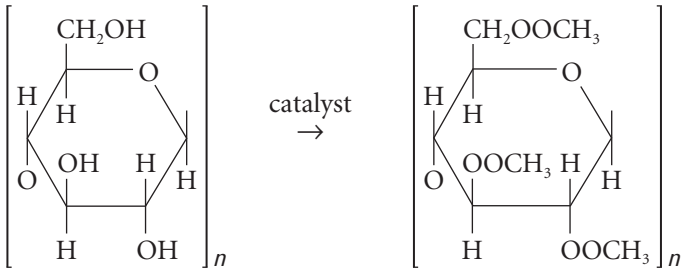
21. What are the distinctive features of carbohydrate molecules that, given a structural formula, would allow you to classify them as carbohydrates?

22. Explain in terms of molecular structure why sugars have a relatively high melting point compared with hydrocarbons of comparable size.

23. Describe, and then explain, the relative solubility of glucose, starch, and cellulose in water.

Cellulose Acetates—Structural Analogs of Polysaccharides

Chemists have researched and developed polymers that are modifications of natural polymers. These natural–synthetic polymers are called **biopolymers**. For example, starch and cellulose have been made into synthetic polymers. An example is cellulose triacetate. Cellulose, a polysaccharide, is modified by reacting it with acetic acid, $CH_3COOH(l)$, and acetic anhydride, $(CH_3CO)_2O(l)$, with sulfuric acid as a catalyst.



cellulose → cellulose triacetate

Cellulose triacetate is a polymer that is used in fabrics such as permanently pleated garments, textured knits, and sportswear. There are other, similar, cellulose acetates.

WEB Activity

Case Study—Cellulose Acetate

This activity leads you through an exploration of the historical and current work done by polymer chemists to use natural polymers to produce synthetic polymers with desired characteristics and applications.

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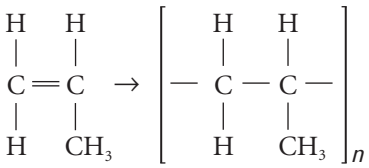
SUMMARY Polymers—Plastics, Fibres, and Food

Polymers are a common part our everyday world and include natural polymers (lipids (triesters), proteins, and carbohydrates) and synthetic polymers (e.g., nylon, cellulose acetate, and polyesters). For the structural formula equations of these polymers, see previous pages.

Addition Polymers

Synthetic Addition Polymer (e.g., polypropene)



Condensation Polymers (Structural Analogs)

Polyesters

- Natural "Polyester" (e.g., butter):
  glycerol + fatty acid $\rightarrow$ fat or oil + water
  e.g., $C_3H_5(OH)_3 + 3\ C_{17}H_{35}COOH \rightarrow C_3H_5(OOCC_{17}H_{35})_3 + 3\ H_2O$
- Synthetic Polyester (e.g., Dacron)
  dicarboxylic acid + polyalcohol $\rightarrow$ polyester + water
  e.g., $HOOC-C_6H_4-COOH + HO-CH_2-CH_2-OH \rightarrow$
  $[-OOC-C_6H_4-COO-CH_2-CH_2-]_n + n\,H_2O$

Polyamides

- Natural (proteins; polypeptides):
  amino acid + amino acid + … $\rightarrow$ protein + water
  e.g., $H_2N-CH_2-COOH + H_2N-CHCH_3-COOH \rightarrow$
  $[-NH-CH_2-CONH-CHCH_3-CO-]_n + n\,H_2O$
- Synthetic (e.g., nylon 6,6):
  dicarboxylic acid + diamine $\rightarrow$ nylon + water
  e.g., $HOOC-(CH_2)_4-COOH + H_2N-(CH_2)_6-NH_2 \rightarrow$
  $[-OC-(CH_2)_4-CONH-(CH_2)_6-NH-]_n + n\,H_2O$

Polysaccharides

- Natural (e.g., starch):
  glucose + glucose $\rightarrow$ starch + water
  glucose + glucose $\rightarrow$ cellulose + water
  (The glucose molecules that polymerize to produce starch or cellulose have slightly different stereochemical formulas.)
  $C_6H_{12}O_6 + C_6H_{12}O_6 \rightarrow [-C_6H_{10}O_5-]_n + n\,H_2O$
- Synthetic (e.g., cellulose triacetate):
  cellulose + acetic acid + acetic anhydride $\rightarrow$ cellulose acetate + ...
  $[-C_6H_{10}O_5-]_n + CH_3COOH + (CH_3CO)_2O \rightarrow [-C_6H_7O_5(OCH_3)_3-]_n + ...$

Learning Tip

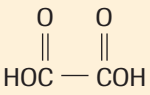
Try to equate the classification of condensation polymers with the three food groups when organizing your knowledge of polymers:

- polyesters include **lipids** and polyester fabrics
- polyamides include **proteins** and polyamide fabrics
- polysaccharides include **carbohydrates** and, for example, cellulose acetate.

Chemists create classification systems to help them organize their knowledge. Use the same approach to your advantage.

Section 10.5 Questions

1. Teflon®, made from tetrafluoroethene monomer units, is a polymer that provides a non-stick surface on cooking utensils. Write a structural formula equation to represent the formation of polytetrafluoroethene.
2. Polyvinyl chloride, or PVC plastic, has numerous applications. Write a structural formula equation to represent the polymerization of chloroethene (vinyl chloride).
3. Using a molecular model kit, construct models of the following monomers and polymers:
   (a) starch
   (b) polyvinyl chloride
   (c) nylon
   (d) polypropene
   (e) a polyester
   (f) cellulose acetate
4. As with most consumer products, the use of polyethylene has benefits and problems. What are some beneficial uses of polyethylene and what problems result from these uses? Suggest alternative substances for each application.
5. Use the information in this section and from your own research to continue gathering perspective statements concerning the statement that we should be saving more fossil fuels for petrochemical use in the future.
6. The first nylon product that was introduced to the public, in 1937, was a nylon toothbrush called Dr. West's Miracle-Tuft toothbrush. Earlier toothbrush bristles were made of hair from animals such as boar. From your knowledge of the properties of nylon, suggest some advantages and drawbacks of nylon toothbrushes compared with their natural counterparts.
7. Oxalic acid is a dicarboxylic acid found in rhubarb and spinach. Its structure is shown below.



   Draw three repeating units of the condensation polymer made from oxalic acid and ethan-1,2-diol.
8. What is the synthetic polymer analog of each of the following foods?
   (a) pasta
   (b) meat
   (c) butter
9. Suppose that two new polymers have been designed and synthesized for use as potting material for plants.
   (a) List and describe the properties of an ideal polymer to be used to hold and supply water and nutrients for a plant over an extended period of time.
   (b) Design an experiment to test and compare the two polymers for the properties you listed. Write a brief description of the procedures followed, and possible interpretations of experimental results.
10. When we purchase a product, we may want to consider not only the source of its components, but also the requirements for its use and maintenance. In your opinion, how valid is the use of the terms "organic," "natural," and "chemical" in the promotion of consumer goods?
11. Starch and cellulose have the same caloric value when burned, but very different food values when eaten by humans. Explain.
12. Explain why the sugars in a maple tree dissolve in the sap but the wood in the tree trunk does not.
13. Many consumer products are available in natural or synthetic materials: paper or plastic shopping bags, wood or plastic lawn furniture, cotton or polyester clothing. Choose one consumer product and list the advantages and disadvantages of the natural and synthetic alternatives, with particular reference to structure and properties of the material used as it relates to the function of the product.
14. Classify the type of polymerization for each of the following polymers:
   (a) polyethenes
   (b) polyesters
   (c) polyamides
   (d) polysaccharides
15. Research or use what you know to write a combination of a word, molecular formula, and structural formula equation for each of the following chemical transformations:
   (a) starch (from grain) to glucose to ethanol
   (b) cellulose (from aspen trees) to glucose to methanol

Extension

16. Alkyd (oil-based) paint is a polyester formed by reacting glycerol ($CH_2OHCHOHCH_2OH$) with 1,2-benzenedicarboxylic acid ($C_6H_4(COOH)_2$). Communicate this reaction using a structural formula equation.
17. What functional group(s), if any, must be present in a monomer of a condensation polymer?
18. In an attempt to reduce body weight, many Canadians are considering low-carbohydrate or low-sugar diets. Based on your knowledge of the chemistry of carbohydrates and sugars, comment on which of these diets might be more effective.
19. Natural rubber is made from resin produced by the rubber tree, *Hevea brasiliensis*.
   (a) Research the history of the use of rubber by Aboriginal peoples long before Europeans came to the Americas.
   (b) Research the commercial invention, production, and use of natural rubber, and the circumstances that stimulated the development of synthetic rubber.
   (c) Write a brief report on your findings.
20. Raymond Lemieux, from Lac La Biche, Alberta, was the first chemist to artificially synthesize sucrose (in 1953). Consult the biographical information of Lemieux. Describe his interest in science and one of his other accomplishments (other than the synthesis of sucrose).

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21. Check the latest Alberta Chemical Operations Directory to see if there are any new monomer and polymer chemical plants in Alberta.

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INVESTIGATION 10.1

Substitution and Addition Reactions

Substitution and addition reactions are two common classes of organic reactions. Substitution reactions are common to saturated hydrocarbons. Addition reactions are common to unsaturated (alkene and alkyne) hydrocarbons. In general, substitution reactions are slower and addition reactions are faster.

Purpose

The purpose of this investigation is to test the generalization that addition reactions are faster than substitution reaction.

Problem

Which compound reacts faster with aqueous bromine: cyclohexane or cyclohexene?

Design

Aqueous bromine is added to samples of cyclohexane and cyclohexene in both the presence and absence of light.

Materials

lab apron
eye protection
4 small test tubes with stoppers
test tube rack (or beaker)
aluminium foil (approx. 10 cm × 10 cm)
dropper bottles of
- cyclohexane
- cyclohexene
- aqueous bromine

Cyclohexane and cyclohexene are flammable. Work in a well-ventilated area. Keep away from sparks or flames.

Bromine is toxic and corrosive. Avoid skin and eye contact. Wash hands thoroughly when finished.

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	● Evaluation (1, 2, 3)
○ Hypothesis	○ Procedure	
● Prediction	● Evidence	

Procedure

1. Add 20 drops of cyclohexane to each of two test tubes and stopper immediately.
2. Cover one of the test tubes up to the rim with aluminium foil.
3. Repeat steps 1 and 2 using cyclohexene and two more test tubes.
4. For each of the four test tubes: remove the stopper briefly to add 10 drops of aqueous bromine.
5. Placing a thumb or finger on the stopper, briefly shake each test tube.
6. Record your observations immediately and again after several minutes. (You will need to momentarily slide the covered test tubes out of the foil to observe.)
7. Dispose of the contents of all test tubes into labelled waste containers.

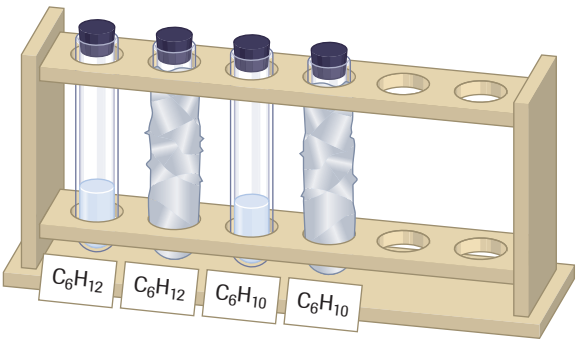

Figure 1
Set-up for reactions of cyclohexane and cyclohexene with and without light

INVESTIGATION 10.2

Isomers of Butanol

Organic halides have many uses, but they are not commonly found in nature. Organic halides must, therefore, be synthesized from other compounds. On an industrial scale, organic halides are produced by addition and substitution reactions of hydrocarbons. A common laboratory-scale process is the halogenation of alcohols in which the hydroxyl group of the alcohol is replaced by a halogen. This reaction requires the presence of a strong acid that contains a halogen, such as hydrochloric acid.

$$\text{R-OH(l)} + \text{HX(aq)} \rightarrow \text{R-X(l)} + \text{H}_2\text{O(l)}$$

Organic halides have much lower solubilities in water compared with their corresponding alcohols.

Purpose

The purpose of this investigation is to test a personal hypothesis about the relative reactivity of the alcohol isomers of butan-1-ol.

Problem

What is the difference in reactivity, if any, of the alcohol isomers of butan-1-ol with concentrated hydrochloric acid?

Design

Samples of butan-1-ol, butan-2-ol, and 2-methylpropan-2-ol are mixed with concentrated hydrochloric acid. Evidence of reaction is obtained by looking for a low-solubility organic halide product (cloudy mixture).

Concentrated hydrochloric acid is corrosive and the vapour is very irritating to the respiratory system. Avoid contact with skin, eyes, clothing, and the lab bench. Wear eye protection, gloves, and a laboratory apron.

All three alcohols are highly flammable. Do not use near an open flame.

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	● Materials	● Evaluation (1, 2, 3)
● Hypothesis	○ Procedure	
● Prediction	● Evidence	

Procedure

1. Add two drops each of butan-1-ol, butan-2-ol, and 2-methylpropan-2-ol into separate small labelled test tubes in a test-tube rack.
2. In the fume hood, add 10 drops of concentrated HCl(aq) to each of the three isomers in the test tubes.
3. Stopper and swirl each of the test tubes gently and cautiously.
4. Back at your laboratory bench, observe the test tubes over a period of a few minutes. Look for cloudiness in the water layer—an indication of the formation of an organic halide.
5. Dispose of the contents of all test tubes in the fume hood into a labelled waste container.

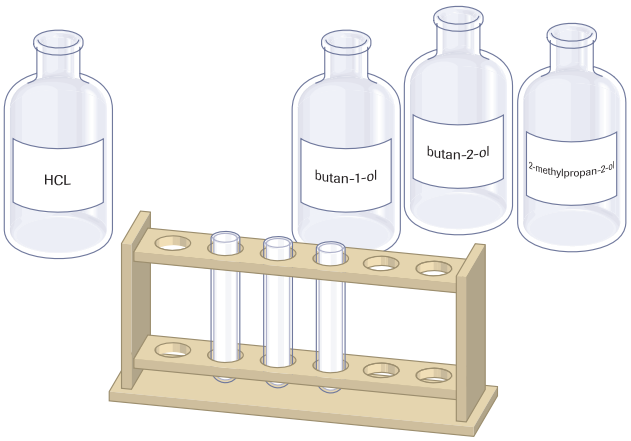

Figure 2
Set-up for testing the reactivity of three butanol isomers

INVESTIGATION 10.3

Synthesis of an Ester

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	○ Evaluation
○ Hypothesis	○ Procedure	
○ Prediction	● Evidence	

Purpose

The purpose of this investigation is to use the esterification generalization and diagnostic tests to synthesize and observe the properties of two esters.

Problem

What are some physical properties of ethyl ethanoate (ethyl acetate) and methyl salicylate?

Design

The esters are produced by the reaction of appropriate alcohols and acids, using sulfuric acid as a catalyst. The solubility and the odours of the esters are observed.

Materials

lab apron
eye protection
dropper bottles of ethanol, methanol, glacial ethanoic (acetic) acid, and concentrated sulfuric acid
vial of salicylic acid (2-hydroxybenzoic acid)
two 25 × 250 mm test tubes
250 mL beaker or polystyrene cup
two 50 mL beakers
two 10 mL graduated cylinders
laboratory scoop
balance
hot plate or hot tap water
thermometer
ring stand with test tube clamp

Concentrated ethanoic and sulfuric acids are dangerously corrosive. Protect your eyes, and do not allow the acids to come into contact with skin, clothes, or lab desks.

Both methanol and ethanol are flammable; do not use near an open flame.

Excessive inhalation of the products may cause headaches or dizziness. Use your hand to waft the odour from the beaker toward your nose. The laboratory should be well ventilated.

Procedure

1. Add about 5 mL of ethanol and 6 mL of ethanoic acid to one of the test tubes.
2. Ask your teacher to add 8 to 10 drops of concentrated sulfuric acid to the mixture.
3. Set up a hot water bath using the 250 mL beaker. (The temperature of the water should not exceed 70 °C.)
4. Clamp the test tube so that the reaction mixture is completely immersed in hot water (**Figure 3**).
5. As a safety precaution to block any eruption of the volatile mixture, invert a 50 mL beaker above the end of the test tube (**Figure 3**).
6. After the reaction mixture heats for about 10 min, rinse the second 50 mL beaker with cold tap water and add about 30 mL of cold water to this beaker.
7. Cool the test tube by running cold tap water on the outside of the tube.
8. Pour the contents of the test tube into the cold water in the 50 mL beaker. Observe and smell the mixture carefully, using the correct technique for smelling chemicals.
9. Repeat steps 1 to 7, using 3.0 g of salicylic acid, 10 mL of methanol, and 20 drops of sulfuric acid.
10. Dispose of all mixtures into the sink with lots of cold running water.

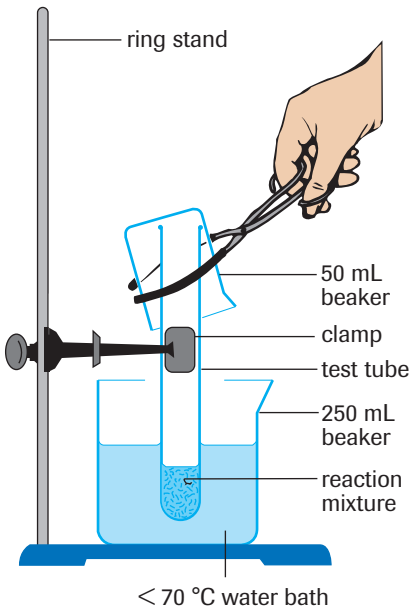

Figure 3
Set-up for synthesis of an ester

INVESTIGATION 10.4

Testing with Models

Molecular models, either physical or electronic, are based on empirically known molecular structures. These models can then be considered as representing evidence collected in a variety of experiments.

Report Checklist

○ Purpose	○ Design	○ Analysis
○ Problem	● Materials	○ Evaluation
○ Hypothesis	○ Procedure	
○ Prediction	● Evidence	

Purpose

The purpose of this investigation is to test stereochemical formula (see Chapter 3) equations by using molecular models.

Problem

What are the stereochemical formula equations for the following reactions?

(a) methane undergoes complete combustion

(b) ethane is cracked into ethene

(c) propane reacts with chlorine

(d) but-2-ene reacts with water

(e) ethanol eliminates water to produce ethene

(f) 1-chloropropane undergoes an elimination reaction with hydroxide ions to produce propene, a chloride ion, and water

(g) ethanol reacts with methanoic acid

Design

Physical or electronic models of the reactants and products for each reaction are constructed. The bonding and shapes of the molecules from the models are compared with the predictions.

INVESTIGATION 10.5

Preparing Nylon 6,10 (Demonstration)

Nylon was considered the "miracle" fibre when it was discovered in 1935. At the time, nylon was unique because it was the first synthetic fibre produced from petrochemicals. It initiated an entire new world of manufactured fibres. In this demonstration, sebacoyl chloride, $COCl(CH_2)_8COCl(l)$, reacts with 1,6-diaminohexane to produce one type of nylon. For the prediction, write a condensed or line structural formula equation showing the formation of the polymer.

Report Checklist

○ Purpose	○ Design	○ Analysis
○ Problem	○ Materials	○ Evaluation
○ Hypothesis	○ Procedure	
● Prediction	● Evidence	

Purpose

The purpose of this demonstration is to use your knowledge of condensation polymerization to explain the formation of a nylon polymer.

Problem

How does the combination of sebacoyl chloride and 1,6-diaminohexane form the polymer known as nylon 6,10?

Design

A solution of 1,6-diaminohexane is carefully poured on top of an aqueous solution of sebacoyl chloride. The nylon that forms at the interface of the two layers is slowly pulled out of the mixture using forceps.

The reactants and solvent used are irritants. Use a fume hood for this demonstration.

Chapter 10 SUMMARY

Outcomes

Knowledge

- identify and describe significant organic compounds in daily life, demonstrating generalized knowledge of their origins and applications (all sections)
- name and draw structural, condensed structural and line diagrams and formulas for organic halides, alcohols, carboxylic acids, and esters (all sections)
- identify types of compounds from their functional groups, given the structural formula and name the functional groups (10.2, 10.3, 10.4)
- compare, both within a homologous series and between compounds with different functional groups, the boiling points and solubility of examples of alcohols and carboxylic acids (10.3, 10.4)
- define, illustrate, and provide examples of simple addition, substitution, elimination, and esterification (condensation) reactions (10.2, 10.3, 10.4, 10.5)
- predict products and write and interpret balanced equations for the above reactions (10.2, 10.3, 10.4, 10.5)
- define, illustrate, and give examples of monomers, polymers, and polymerization in living and non-living systems (10.5)
- relate the reactions described above to major reactions for producing economically important compounds from fossil fuels (all sections)

STS

- illustrate how science and technology are developed to meet societal needs and expand human capabilities (all sections)
- describe interactions of science, technology, and society (all sections)
- illustrate how science and technology have both intended and unintended consequences (10.5)

Skills

- initiating and planning: predict the ester formed from an alcohol and an organic acid (10.4); describe procedures for safe handling, storing and disposal of materials used in the laboratory, with reference to labelling information (10.2, 10.3, 10.4, 10.5); design an experiment to compare the properties of organic to inorganic compounds (10.4)
- performing and recording: build molecular models depicting the structures of selected organic and inorganic compounds (10.4); perform an experiment to investigate the reactions of organic compounds (10.2, 10.3, 10.4, 10.5)
- analyzing and interpreting: follow appropriate IUPAC guidelines in writing the names and formulas of organic compounds (all sections); compile and organize data to compare the properties of structural isomers (10.3); interpret results of a test to distinguish between a saturated and an unsaturated aliphatic using aqueous bromine solution (10.2); use appropriate chemical symbols and nomenclature in writing organic chemical reactions (all sections); use models to illustrate polymerization (10.5)
- work cooperatively in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results (10.3, 10.4, 10.5)

Key Terms

10.2

hydrocarbon derivative
organic halide
functional group
addition reaction
substitution reaction

10.3

alcohol
hydroxyl group
elimination reaction

10.4

carboxylic acid
carboxyl group
condensation reaction
ester
esterification reaction
ester functional group

10.5

polymer
monomer
polymerization
addition polymerization
condensation polymerization
polyester
polyamide
polypeptide

MAKE a summary

1. Draw a map of Alberta and indicate at least one location where each of the following chemicals is produced: ethane, ethene, ethylene glycol, methanol, polyethene, polyvinyl chloride, styrene. For each chemical, indicate the reaction type and illustrate the reaction with a structural formula equation.
2. Refer back to your answers to the Starting Points questions at the beginning of this chapter. How has your thinking changed?

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The following components are available on the Nelson Web site. Follow the links for *Nelson Chemistry Alberta 20–30*.

- an interactive Self Quiz for Chapter 10
- additional Diploma Exam-style Review questions
- illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in this chapter.

Chapter 10 REVIEW

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix H. Exam study tips and test-taking suggestions are on the Nelson Web site. Science Directing Words used in Diploma Exams are in bold type.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. There are arguments pro and con from a variety of perspectives for saving our fossil fuels for petrochemical production for generations to come. Which of the following statements is *not* classified correctly?
   A. economic: We need the corporate profit and individual salaries now.
   B. legal: It isn't right for us to be burning these irreplaceable fossil fuels.
   C. ethical: This resource doesn't just belong to us; it belongs to future generations.
   D. social: Families and communities need the resource development now.

2. The organic compound ethane-1,2-diol is manufactured in Alberta from the primary petrochemical
   A. ethene
   B. propene
   C. methanol
   D. benzene

3. The type of chemical reaction that involves breaking a carbon–hydrogen bond and replacing the hydrogen atom with another atom or group of atoms is called
   A. addition
   B. substitution
   C. condensation
   D. esterification

Use the names of these organic compounds to answer questions 4 and 5.

1. gasoline additive, ethanol
2. glycerol, propane-1,2,3-triol
3. PVC monomer, chloroethene
4. organic solvent, ethyl ethanoate
5. pineapple odour, ethyl butanoate
6. radiator antifreeze, ethane-1,2-diol
7. wintergreen odour, methyl salicylate
8. banana odour, 3-methylbutyl ethanoate
9. used to manufacture acetone, propan-2-ol

4. NR In numerical order, the alcohols are ____, ____, ____, and ____.

5. NR In numerical order, the esters are ____, ____, ____, and ____.

6. Chemists were initially surprised that the reaction of benzene and chlorine to form chlorobenzene and hydrogen chloride is an example of a(n)
   A. addition reaction
   B. elimination reaction
   C. esterification reaction
   D. substitution reaction

7. Chemists predict, based on a generalization, that the reaction between methanol and propanoic acid produces water and
   A. propanol
   B. propyl methanoate
   C. methyl propanoate
   D. methanoic acid

8. A generalization supported by laboratory evidence suggests that bromine and propene react to produce
   A. 1-bromopropane
   B. 2-bromopropane
   C. 1,1-dibromopropane
   D. 1,2-dibromopropane

There are more compounds of carbon than compounds of all other elements combined. Use this short list of carbon compounds to answer questions 9 to 12.

1. butanoic acid
2. butan-1-ol
3. ethanoic acid
4. ethanol
5. hexan-1-ol
6. methylpropane
7. octan-1-ol
8. propanoic acid
9. pentanoic acid

9. NR From lowest to highest, the order of boiling points of the alcohols is ____, ____, ____, and ____.

10. NR From lowest to highest, the order of solubility of the alcohols is ____, ____, ____, and ____.

11. NR From lowest to highest, the order of solubility of the acids is ____, ____, ____, and ____.

12. NR The two compounds that must react to form ethyl butanoate are ___ and ___ ___ ___.

13. The functional group, —COOH, is characteristic of
   A. esters
   B. alcohols
   C. aromatics
   D. carboxylic acids

14. Which of the following substances is an addition polymer?
   A. protein
   B. polyester
   C. polypropylene
   D. polysaccharide

Part 2

15. **Identify** the category, and draw a line structural formula, for each of the following organic compounds.
(a) triiodomethane
(b) 1,2-difluoroethene
(c) propane-1,2,3-triol
(d) 2-methylpropan-2-ol
(e) propanoic acid
(f) methyl butanoate
(g) phenol
(h) 1,3-dibromobenzene
(i) benzoic acid
(j) ethyl benzoate

16. Complete the following word equations and draw complete structural formula equations for each of the following organic reactions.
(a) butane + chlorine →
(b) but-1-ene + hydrogen chloride →
(c) chloroethane + hydroxide ion →
(d) benzene + fluorine →
(e) benzoic acid + ethanol →
(f) propene + bromine →
(g) propan-1-ol + ethanoic acid →

17. Alcohols, carboxylic acids, and esters are generally more soluble in water than the corresponding alkanes. Draw structural formulas for simple 3-carbon molecules from each of these families and **explain** why they are more soluble in water than propane.

18. DE **Explain** the difference between addition and condensation polymers. Your response should include
- characteristics of the monomers
- products of the polymerization reaction

19. **Identify** what special precautions must be taken when working with and disposing of organic compounds.

20. Because of side reactions in organic reactions, the yield of desired product is often low, and is usually expressed as a % yield. Complete the Analysis of the investigation report.

Problem

What is the percent yield in the esterification reaction between pentanol and butanoic acid to form pentyl butanoate?

Design

An excess of pentanol reacts with a measured mass of butanoic acid in the presence of a sulfuric acid catalyst. The product is separated from the reaction mixture by fractional distillation.

Evidence

mass of butanoic acid reacted = 2.00 g
mass of pentyl butanoate obtained = 1.32 g

21. **Design** an experiment to distinguish alkanes from alkenes. Assume the hydrocarbons are in the liquid phase.

22. Write IUPAC names for the following organic compounds.
(a) $CH_3—CH_2—CH_2—CHF—CH_2F$
(b) $CH_3—CH_2—CH_2—CH_2OH$
(c) $CH_3—CH_2—CH_2—CH_2—COOH$
(d) $CH_3—CH_2—COO—CH_2—CH_3$
(e) $CH_2OH—CHOH—CH_2OH$
(f) $CH_3—CH_2—COOH$
(g) $CH_3—CH_2—COO—CH_2—CH_2—CH_3$
(h) $CH_3—CHBr—CH_2—CH_2Br$

23. Draw a line structural formula for each of the following aromatic compounds.
(a) 1,4-dichlorobenzene
(b) benzoic acid
(c) phenol
(d) methyl benzoate
(e) 1,2,3-tribromobenzene
(f) ethyl benzoate

Use the following information to answer questions 24 to 26.

The field of polymer chemistry has blossomed since Carothers' discovery of nylon in 1935. Thousands of new polymers have now been developed, including Teflon, polystyrene, polypropylene, and polyvinyl chloride.

Polymers have been very beneficial in many ways. They have also, however, introduced problems for many societies around the world.

24. DE (a) **Identify** the class of synthetic polymers into which all of the named compounds (above) fall.
(b) Name and draw structural formulas for the monomers used to produce each of the four polymers.
(c) What feature do these monomers have in common? **Explain** how this enables polymerization to occur. **Illustrate** your explanation with a structural formula reaction equation.

25. **Explain** why the monomers used to produce condensation polymers must be bifunctional (have two functional groups).

26. DE **Compare** the impacts of polymers on two different societies: one urban and relatively wealthy; one rural and relatively poor. Your response should include
- a variety of perspectives
- benefits and drawbacks of the development of synthetic polymers
- suggestions for alternatives to synthetic polymers
- an answer to the question: On balance, do synthetic polymers benefit humanity?

27. Consider the Resolution in the Exploration that began this chapter. Respond to the Resolution with the production and use of polymers in mind.

Unit 5 REVIEW

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix H. Exam study tips and test-taking suggestions are on the Nelson Web site. Science Directing Words used in Diploma Exams are in bold type.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

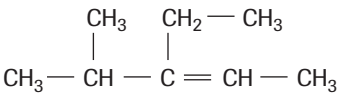
1. Alberta refines and manufactures many organic compounds. The Alberta product that is not considered an organic compound is
A. gas line antifreeze, $CH_3OH(l)$
B. vinegar, $CH_3COOH(aq)$
C. limestone, $CaCO_3(s)$
D. natural gas, $CH_4(g)$

2. Which one of the following organic compounds is *least* likely obtained from a natural gas well?
A. methane
B. ethane
C. propane
D. benzene

3. NR There are many organic compounds that are important in daily life. Match the compounds listed with the applications.
1 gasoline additive
2 plastic wrap
3 barbecue fuel
4 natural sweetener

When the common applications for propane, ethanol, sucrose, and polyethylene are listed in order, the order is __, __, __, and __.

4. The IUPAC name for the following possible component of gasoline is

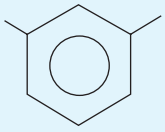


A. 2-methyl-3-ethylpent-3-ene
B. 3-ethyl-4-methylpent-2-ene
C. 2-methyl-3-ethylpent-2-ene
D. 2,3,3-trimethylpent-2-ene

5. The boiling points, from smallest to largest members of an aliphatic family
A. increase
B. decrease
C. stay relatively constant
D. increase initially, and then decrease

Use this information to answer questions 6 and 7.

Xylenes are important aromatics used in a variety of applications, such as solvents and as raw materials for the production of polyester fibres, dyes, and insecticides. The structure of one particular xylene is



6. The IUPAC name for this xylene is
A. 1,3-dimethylcyclohexane
B. ethylbenzene
C. 2,6-dimethylbenzene
D. 1,3-dimethylbenzene

7. A structural isomer of this xylene is
A. octane
B. ethylcyclohexane
C. ethylbenzene
D. 1,3-dimethylhex-1-ene

8. Which one of the following technological processes is *not* used to physically separate organic compounds from a mixture?
A. solubility
B. hydrocracking
C. solvent extraction
D. fractional distillation

9. The most likely reaction between an alkene and chlorine is
A. addition
B. combustion
C. elimination
D. substitution

10. Which of the following organic reactions is most likely to produce an alkene?
A. $C_3H_6 + Cl_2 \rightarrow$
B. $C_4H_8 + H_2 \rightarrow$
C. $CH_3(CH_2)_2COOH + CH_3(CH_2)_2OH \rightarrow$
D. $CH_2ClCH_3 + OH^- \rightarrow$

11. Which of the following chemical equations represents a catalytic reforming reaction?
A. $C_6H_6 + I_2 \rightarrow C_6H_5I + HI$
B. $CH_3(CH_2)_5CH_3 \rightarrow C_6H_5CH_3 + 4\ H_2$
C. $C_2H_5COOH + C_2H_5OH \rightarrow C_2H_5COOC_2H_5 + H_2O$
D. $2\ C_4H_{10} + 13\ O_2 \rightarrow 8\ CO_2 + 10\ H_2O$

Use this information to answer questions 12 to 15.

Scientists create classification systems to help them organize their knowledge and develop generalizations to make predictions. Classify the following organic reactions as requested.

1. $C_3H_6 + Cl_2 \rightarrow C_3H_6Cl_2$
2. $CH_3CH_2ClCH_3 + OH^- \rightarrow CH_3CHCH_2 + H_2O + Cl^-$
3. $C_3H_8 \rightarrow C_3H_6 + H_2$
4. $C_3H_8 + Br_2 \rightarrow CH_3CHBrCH_3 + HBr$
5. $C_{12}H_{26} + H_2 \rightarrow C_7H_{16} + C_5H_{12}$
6. $C_2H_5OH \xrightarrow{H^+} C_2H_4 + H_2O$
7. $C_8H_{18} + H_2 \rightarrow 2\,C_4H_{10}$
8. $C_4H_8 + H_2 \rightarrow C_4H_{10}$
9. $C_6H_6 + Cl_2 \rightarrow C_6H_5Cl + HCl$

12. In numerical order, the substitution reactions are
NR ____ ____ ____ ____.

13. In numerical order, the addition reactions are
NR ____ ____ ____ ____.

14. In numerical order, the hydrocracking reactions are
NR ____ ____ ____ ____.

15. In numerical order, the elimination reactions are
NR ____ ____ ____ ____.

Use this information to answer questions 16 to 19.

The most severe test of a generalization is its ability to predict. Predict the correct reaction product(s) for each organic reaction below. Some of the reactions have only one product. You may use the same number more than once.

1. 1-chloropropene
2. 2-chloropropane
3. prop-1-ene
4. propan-2-ol
5. carbon dioxide
6. hydrogen chloride
7. water vapour

16. propane + chlorine → ____ + ____
NR

17. propene + hydrogen chloride → ____ + ____
NR

18. propane + oxygen → ____ + ____
NR

19. propene + steam → ____ + ____
NR

Part 2

20. **Describe**, in words or using a chart, how you would classify an organic compound given its structural formula. Include all classes of organic compounds discussed in this unit.

21. **Design** an experiment to distinguish pure organic compounds from pure inorganic compounds. Include as many different methods as possible.

22. Fossil fuels are of major importance to Alberta. List the different kinds of fossil fuels found in Alberta. For each kind, state one or two major uses.

Use this information to answer questions 23 to 26.

Dow Chemical Canada Inc. (**Figure 1**) has extensive chemical operations in Prentiss and Fort Saskatchewan, Alberta. The major products produced are: hydrochloric acid, Styrofoam® (extruded polyphenylethene (polystyrene) insulation), vinyl chloride monomer (chloroethene), 1,2-dichloroethane, sodium hydroxide, chlorine, ethylene (ethene), and polyethylene. The sites are also home to MEGlobal Canada, which produces ethylene glycol (ethane-1,2-diol).

Figure 1
Dow Chemical Canada Inc.

23. Classify each of the products produced by Dow Chemical as organic or inorganic.

24. Draw full structural formulas for as many of the organic products produced at Dow Chemical's sites as possible. Circle functional groups and identify the organic family.

25. Suggest a possible chemical reaction for the production of 1,2-dichloroethane using only the substances produced by Dow Chemical.

26. Some of the substances produced by Dow Chemical are intermediates used to manufacture other substances, and some substances may show up in final products. From the list given, **identify** any substances that consumers are able to buy in stores. For each of these substances, state a typical use.

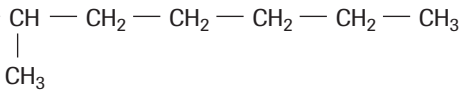
Use this information to answer questions 27 to 29.

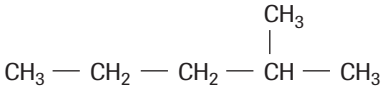
Catalytic reforming is an important process in the modern oil refining industry. Catalytic reforming is used to produce aromatics to improve the quality of gasoline and as a starting material for the petrochemical industry. An overview of the catalytic reforming process is

C_6 to C_8 alkanes $\rightarrow$ cycloalkanes/enes $\rightarrow$ simple aromatics
(naphtha feedstock) (intermediates) (final products)

27. Write the IUPAC name for each of the following hydrocarbons in a naphtha feedstock:

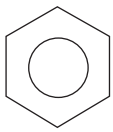
(a) $CH_3 - (CH_2)_6 - CH_3$

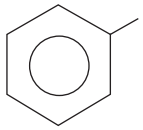
(b) 

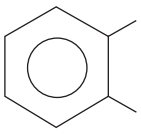
(c) 

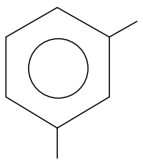
28. Draw a line structural formula for each of the following intermediates from catalytic reforming:
(a) cyclohexane
(b) 1-methylcyclopentene
(c) 1,2-dimethylcyclohexane

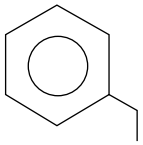
29. Write the IUPAC name for each of the following aromatic products from catalytic reforming:

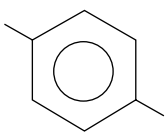
(a) 

(b) 

(c) 

(d) 

(e) 

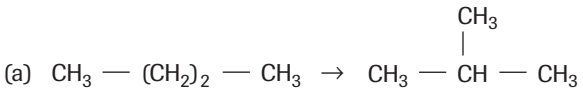
(f) 

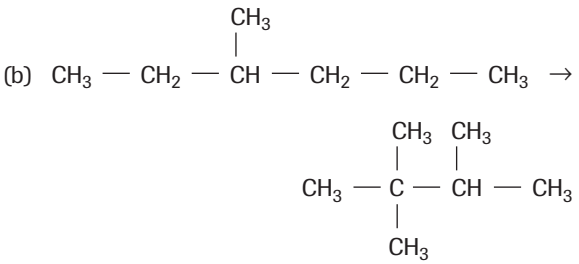
Use this information to answer questions 30 to 32.

Many new technologies are being developed for oil refining. One example is alkylation (isomerization). This process is used to produce more branching in alkanes and also to produce isomers of simple aromatics.

30. Using your knowledge of the term "isomers," **describe**, in your own words, the process of alkylation (isomerization).

31. For each of the following isomerization reaction equations, write IUPAC names or draw condensed structural formulas as required:

(a) 

(b) 

(c) heptane $\rightarrow$ 2,4-dimethylpentane
(d) octane $\rightarrow$ 2-methyl-3-ethylpentane

32. What chemical process increases the octane rating by increasing the aromatic character of the gasoline?

33. DE The following compounds contain molecules that have approximately the same number of electrons: chloroethene, ethanoic acid, propan-1-ol, and butane.
(a) Draw a full structural formula of each molecule.
(b) Using the theoretical rules of intermolecular bonding, arrange these substances in order of increasing boiling points. Briefly explain the order.
(c) **Predict** which substances would likely have a high solubility in water and which would have a low solubility. **Justify** your answer.

34. For each of the following reactions of one mole of an organic reactant, **predict** the chemical amount of hydrogen required for a complete reaction:
(a) $CH_2{=}CH{-}CH{=}CH_2 + H_2 \rightarrow$
(b) $CH{\equiv}C{-}CH_2{-}CH_2{-}C_6H_5 + H_2 \rightarrow$
(c) $C_7H_{14} + H_2 \rightarrow$

35. Cycloalkanes have structural isomers that are alkenes. **Design** an experiment to distinguish between an alkene and a cycloalkane that are structural isomers of each other. Provide the Design, including diagnostic tests.

Problem

Which sample of C_6H_{12}(l) is an alkene isomer, and which is a cycloalkane isomer?

Use this information to answer questions 36 and 37.

Petroleum products with double and triple bonds can polymerize, and form waxy deposits that plug pipe systems and pipelines. One purpose of hydrotreating is to remove multiple bonds to stabilize the liquids, so that polymerization in pipes does not occur.

36. Write a structural formula equation for the addition polymerization of ethene (ethylene) molecules, showing how two molecules can attach to each other and have a free bond at each end for further attachments.

37. Write a structural formula for a section of a polymer of propene (propylene) showing at least four monomer units in the section.

---

38. Suggest a reaction equation or a sequence of reaction equations to synthesize each of the following organic compounds:
(a) ethanol (common solvent; component of alcoholic beverages and gasohol)
(b) propene (monomer for polypropylene plastic)
(c) dichlorodifluoromethane (CFC-12, a refrigerant)
(d) Teflon® polymer
(e) ethyl ethanoate (solvent)

39. For each of the following reactions, draw structural formulas for all reactants and products, name the products, and classify the reaction type.
(a) cyclohexane + chlorine $\rightarrow$
(b) 2-phenylpropane + oxygen $\rightarrow$
(c) 2,3-dimethylbut-2-ene + hydrogen chloride $\rightarrow$
(d) octane $\rightarrow$ ethylbenzene
(e) butan-1-ol + methanoic acid $\rightarrow$
(f) 2-bromohexane + hydroxide ion $\rightarrow$
(g) decane + hydrogen $\rightarrow$ butane + hexane

40. DE (a) Given that octane has a density of 0.70 kg/L and assuming that gasoline is octane, **predict** the volume of octane that will produce 1.0 t of carbon dioxide by complete combustion in an automobile engine.
(b) How far could you drive a typical car on that much gasoline? (Assume 10 L/100 km.)

41. Copy and complete **Table 1**.

Table 1 Some Important Organic Compounds

IUPAC name	Condensed structural formula	Organic family	Common use
	$CH_2 = CH_2$		
ethane-1,2-diol			
tetrachloroethene			degreaser for metal components
	$CH_3 - (CH_2)_6 - CH_3$		
ethyl ethanoate			fingernail polish solvent
methylbenzene			gasoline component; solvent
			vinegar
		alkyne	welding and cutting torch

42. Side reactions and byproducts are common for organic reactions. The yield of a product is often expressed as a % yield. Complete the Analysis of the investigation report.

Problem
What is the percent yield in the initial substitution reaction between methane and chlorine?

Design
A quantity of methane reacts with chlorine gas. The products of the reaction are separated by condensation of the gaseous products into separate fractions.

Evidence
mass of methane reacted = 1.00 kg
mass of chloromethane produced = 2.46 kg

43. DE Fossil fuels come with various physical and chemical properties. As a result of these properties, they are refined by different processes and used in different ways.
(a) List the fossil fuels of Alberta, from most dense to least dense.
(b) **Describe** two differences between the refining of natural gas and the refining of crude oil.
(c) **Evaluate**, with reasoning and evidence, the statement: "Gasoline must contain significant quantities of nitrogen because nitrogen oxides are found in the exhaust of cars and trucks."

44. DE Methane is produced naturally by a number of sources and becomes part of the hydrocarbon component in the atmosphere of Earth. Human technologies also contribute to atmospheric hydrocarbons.
(a) **Identify** two natural sources and two technological sources of atmospheric methane.
(b) Methane is a greenhouse gas. **Define** a greenhouse gas.
(c) **Identify** some other greenhouse gases and their sources.
(d) **Describe** actions you can take to reduce the quantity of hydrocarbon molecules that you may allow to escape into the atmosphere.

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45. Copy and complete **Table 2**.

Table 2 Common Monomers

IUPAC name	Chemical formula	Polymer name	Type of polymer
tetrafluoroethene		Teflon®	
benzene-1,4-dicarboxylic acid		Dacron®	
ethane-1,2-diol			
chloroethene		PVC	
benzene-1,3-dicarboxylic acid		alkyd resin	
propane-1,2,3-triol			
phenylethene		styrene	
amino acids		proteins	
1,1-dichloroethene		Saran®	
glucose		starch	
propene		polypropylene	

Use this information to answer questions 46 to 49.

Greenhouse gas (GHG) emissions from internal combustion engines in transportation vehicles are a major concern for environmental chemists. Statistics Canada gathers data over time to provide citizens and scientists with information such as that presented in **Table 3**. Use this table, or a more recent one from StatsCan, to answer the following questions.

Table 3 Greenhouse Gas Emissions by Road Transportation Source

Transportation source	CO_2 (kt) 1990	CO_2 (kt) 2001	CH_4 (kt) 1990	CH_4 (kt) 2001	N_2O (kt) 1990	N_2O (kt) 2001	CO_2[1] (kt) 1990	CO_2[1] (kt) 2001	Change %
Gasoline automobiles	51 600	46 400	9.0	4.6	6.3	7.3	53 700	48 700	−9.3
Light duty gasoline trucks	20 400	36 400	4.0	4.8	4.2	9.0	21 800	39 400	80.7
Heavy duty gasoline vehicles	2 990	3 930	0.4	0.6	0.4	0.6	3 140	4 130	31.5
Motorcycles	225	236	0.2	0.2	0.0	0.0	230	242	5.2
Diesel automobiles	657	583	0.0	0.0	0.0	0.0	672	596	−11.3
Light duty diesel trucks	577	629	0.0	0.0	0.0	0.0	591	643	8.8
Heavy duty diesel vehicles	24 300	38 200	1.2	1.9	0.7	1.1	24 500	38 600	57.6
Propane and natural gas vehicles	2 160	1 100	1.7	1.7	0.0	0.0	2 210	1 140	−48.4
Transportation total	103 000	127 000	16.0	14.0	12.0	19.0	107 000	134 000	25.2

[1] CO_2-equivalent emissions are the weighted sum of all greenhouse gas emissions. The following global warming potentials are used as the weights: $CO_2 = 1$; $CH_4 = 21$; $N_2O = 310$.

46. **Identify** the top three road transportation sources for each of carbon dioxide, methane, and nitrous oxide.

47. **Identify** the road transportation source that had the greatest increase and greatest decrease in carbon-dioxide-equivalent emissions over the period.

48. **Determine** the percentage contribution of the chemical with the largest contribution to GHG emissions in each year presented.

49. List, in increasing weighted order, the least to the most individually problematic chemicals as greenhouse gases.

50. Who owns what? Traditional Aboriginal environmental views are generally that resources are gifts and that land cannot be owned, whereas Canadian law allows for ownership and exploitation of the land and its resources. Even ownership is subject to change as laws change, however. Who should change their views or practices? Is there a compromise that can or should be considered? Consider the issue from several perspectives. Briefly state your views relative to the fossil fuel industry.

51. DE Sulfur in gasoline is a pollution problem. Research indicates that refined gasoline may contain anywhere from 30 ppm to 1000 ppm sulfur content. Some jurisdictions have legislated a maximum sulfur content at 30 ppm, which adds one to three cents per litre to the cost of gasoline.

(a) Nonanethiol, $CH_3(CH_2)_8SH(l)$, is one of many possible sulfur-containing components of gasoline. Write the balanced chemical equation for the complete combustion of this compound.

(b) Briefly **describe** the pollution problems that sulfur in gasoline causes.

(c) Are you willing to pay the extra price for low-sulfur gasoline? **Justify** your answer.

52. DE Oil sands extraction and upgrading requires chemical engineers to use many chemical concept. The concepts presented in this unit get you started on understanding the chemistry of the oil sands.

Solubility is an important concept used in the oil sands industry. The following three processes are technological applications of solubility.

- Water is used to separate the bitumen from the sand.
- When oil sands dry, the water layer between the bitumen and the sand is removed and the hot-water separation of the bitumen from the sand is no longer possible.
- Naphtha is used to dilute the bitumen for transportation.

Another technological process used by the oil sands industry is the thermal coking of bitumen to crack large hydrocarbon molecules into smaller molecules and coke (carbon). Many of the products of coking are hydrotreated to remove sulfur, nitrogen, and multiple bonds from the molecules.

(a) Use the concept of solubility to **explain** why the three processes, listed above, work.

(b) Draw line structural formulas for the following products of coking.
  (i) ethylbenzene
  (ii) 4-methylhex-2-ene
  (iii) 6-ethyl-2,3,5-trimethyloctane

(c) Draw structural formulas to complete the following catalyzed hydrotreating reactions.
  (i) 2,4,5-trimethyloct-2-ene + hydrogen $\rightarrow$
  (ii) hept-3-yne + excess hydrogen $\rightarrow$

53. Complete the Exploration of the two issues identified at the beginning of Chapters 9 and 10. Decide on the type of report and complete this report. (See Appendix D.2.)

54. Review the focusing questions on page 352. Using the knowledge you have gained from this unit, briefly **outline** a response to each of these questions.

Extension

55. Ethene has many uses, including the ripening of fruit and vegetables. List six examples of fruit and vegetables that you eat, along with ethylene production by the fruit or vegetable, and the ethylene sensitivity of the fruit or vegetable.

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56. Alberta has an extensive chemical industry that is the second-largest manufacturing industry in the province, producing about ten billion dollars' worth of products annually. List the four main segments of the Alberta chemical industry. Which one is the largest of the four? What is the main basis of this segment? **Describe** some employment opportunities in the Alberta petrochemical industry.

57. BP Amoco has a linear alpha olefin (LAO) plant in Joffre, Alberta that is producing 250 kt of LAO annually. What are LAOs? Write the IUPAC name and draw the structural formula for a few simple LAOs. **Describe** some major applications for small, medium, and large LAOs.

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58. Research matters. Research is at the heart of all advances and innovations in science and engineering. Search the Internet for information on E10 and E85 ethanol blends, oxydiesel, and/or P-series fuels to gain an understanding of the current research programs involving gasohols.

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59. In-situ oil sands processes include steam-assisted gravity drainage (SAGD) and hydrocarbon-gas injection (e.g., Vapex). In hydrocarbon-gas injection, propane and/or butane is injected (with or without steam) into the oil sands seam. The hydrocarbon acts as a solvent to reduce the viscosity of and extract the bitumen. The bitumen solution is collected in a recovery pipe below the injection pipe. View and/or find an animation to view this process. **Outline** several advantages of the hydrocarbon gas process over the SAGD process.

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60. Solvent extraction can be used to remove waxes from crude oil. Two solvents may be used: toluene (methylbenzene), which dissolves the hydrocarbon-oil, and methyl ethyl ketone ($CH_3COC_2H_5$), which dissolves the ester-wax but precipitates it when the temperature is dropped. **Explain**, using structural formulas and solubility theory, the solubility of hydrocarbon oil in toluene and the solubility of wax in methyl ethyl ketone.

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